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THE UNIVERSITY OF ALBERTA

FIRE HISTORY AND FUEL APPRAISAL STUDY OF KANANASKIS PROVINCIAL PARK, ALBERTA

by

© BRAD C. HAWKES

A THESIS

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DEDICATION

This thesis is dedicated to Lorraine and my parents for their support and guidance.

ABSTRACT

A knowledge of fire history, fuel appraisal, lightning and man-caused risk, and fire weather information is essential in resource management planning where forest fire is a consideration. The purpose of this study was to document fire history and fire potential basic to management planning in Kananaskis Provincial Park. The specific objectives were; 1) to document the fire history of Kananaskis Provincial Park; 2) to estimate fuel loading, fire hazard, and resistance to control (using handtools) for selected fuel types; 3) to estimate lightning and man-caused risk and fire weather distributions.

A fire chronology was developed for the period 1586-1978 from fire-scarred tree wedges, age-class data and Alberta Forest Service records. The dates of 20 fires were identified and fire-year maps were constructed for the period 1712 to 1973. Major fires (>1000 hectares) occurred during 1920, 1904, 1890, 1858, 1840, 1803, 1765, 1743, 1732, 1728 and 1712 with a mean fire return interval (M.F.R.I.) of 21 years and a range of 11 to 38 years. The M.F.R.I. for all fires in the Park was 14 years with a range of 2 to 38 years. Significant differences were found for M.F.R.I. due to elevation, aspect and ecological subzone.

A correlation between fire years in Kananaskis Provincial Park and a maximum latewood density chronology for Peyto Lake, Alberta indicated that climate was the major

environmental factor in the occurrence of fires in the Park.

A stand origin map showed extensive areas in the Lower Kananaskis Valley covered by even-aged lodgepole pine stands as a result of the 1920, 1890 and 1858 fires. Most fires in the lower elevation sections of Kananaskis Provincial Park (<2000 m) seemed to have been large (>1000 ha) stand-destroying fires of medium to high fire intensities.

Prevailing south and west winds during July and August seemed to be a critical factor in the behavior of fires. These months also represent the important fire weather season.

Fine (≤7.6 cm) and coarse (>7.6 cm) dead and down fuel loading showed significant differences among fuel types. Dead and down fuel loading differences among fuel types were largely due to differences in site (soil, slope, aspect and elevation) and fire history, and their combined effects on fuel succession. Humus, moss, shrub, herb and crown biomass varied significantly among fuel types.

Crowning potential and resistance to control varied significantly among fuel types. Fuel types were rated for initial rate of spread based on differences in fine fuel loading (<2.5 cm), and for fire intensity based on differences in available dead and down fuel.

Alberta Forest Service fire records indicated that during the period 1959-1977, an average of .84 man-caused fires/year and .26 lightning fires/year, were reported.

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I. INTRODUCTION

Fire has played an important role in the ecology of northern Rocky Mountain forests (Habeck and Mutch 1973). Fire history studies in Alberta have indicated that fire frequencies, sizes and intensities have varied in different forest ecosystems (Byrne 1968, MacKenzie 1973, Tande 1977). This fire history information is an essential element in describing forest ecosystems, development of resource management alternatives, and implementation of programs in fire management planning and operations (Arno 1976). In addition to fire history information, the potential behavior of fires in wildland vegetation must be estimated in order to effectively control and use fire.

An appraisal of wildland vegetation fuels is needed to estimate potential fire behavior (Anderson 1974). Knowledge of fuel quantity and distribution in wildland fuel complexes has long been recognized as an important requirement for predicting fire behavior (Muraro 1971). Fuel classification helps define land units called fuel types according to their characteristics respecting fire spread and difficulty of establishing and holding fire control lines (Hornby 1935). The use and control of fire requires a thorough knowledge of fire behavior, suppression principles and procedures, and fire effects (Robinson 1970). In addition to fire history and fuel appraisal, the factors of lightning and man-caused risk, and fire weather information are essential in

preparing a resource management plan for any area where forest fire is a consideration.

Kananaskis Provincial Park was selected for this study for several reasons. The first reason was that frequencies, sizes and intensities of fires in high elevation (>1500 metres) forests of the Canadian Rocky Mountains have not been investigated in detail. The second reason was that fire-fuel relationships also have not been investigated in detail in these forests. In addition, the recent creation of Kananaskis Provincial Park provided an opportunity to include the collection of fire history and fuel appraisal information as part of the overall resource inventory of the Park.

The purpose of this study was to document fire history and estimate fire potential in support of management planning in Kananaskis Provincial Park. The specific objectives of this study were: 1) to document the fire history of Kananaskis Provincial Park; 2) to estimate fuel loading, fire hazard, and resistance to control (using handtools) for selected fuel types; 3) to estimate lightning and man-caused risk and fire weather distributions for Kananaskis Provincial Park.

These objectives were achieved using a variety of methods. The fire history was documented using a fire-scar analysis, a stand age-class inventory, examination of historical and Alberta Forest Service fire records, and interpretation of aerial photographs. Fuel loading was

evaluated using various sampling procedures to estimate fuel loading directly or indirectly. A simplified fire hazard rating was developed based on crowning potential, initial rate of spread and fire intensity. Resistance to control was estimated using Murphy and Quintilio's (1978) key. Significance of differences in fuel loading, crowning potential and resistance to control among fuel types was tested using analyses of variance and multiple comparison tests. Lightning and man-caused risk was estimated using Alberta Forest Service fire records. Fire weather distributions were estimated using weather records from Kananaskis Fire Lookout.

Subsequent chapters discuss the study in detail. A literature review is presented in Chapter II showing the natural role of fire in North American forest ecosystems, the importance of fuel appraisal information and how this information is incorporated in resource management planning. Chapter III describes the research area and provides basic information on the climate, vegetation and resources of the Park. The remaining chapters discuss fire history and fuel appraisal methods, results and discussion. A summary and conclusions chapter is followed by recommendations for fuels and fire management in Kananaskis Provincial Park.

II. LITERATURE REVIEW

A. The Natural Role of Fire

Many biotic communities of North America are fire-dependent. Fire has been an inevitable process of biological significance (Mutch and Aldrich 1973). Fire is the key environmental factor that initiates new successional sequences, controls species composition and age structure of the forests, and produces the vegetation "fire mosaics" upon which the animal components of the ecosystem depend (Heinselman 1970).

Many plants and animals are adapted to the cyclic occurrence of wildland fires. The interaction between fire and terrestrial ecosystems over evolutionary and successional time scales has led to adaptations which enable many plants and animals to survive in a fire environment (Mutch and Aldrich 1973).

The adaptation of plants to fire can be viewed in two categories: 1) adaptations which increase the fire resistance of plants and 2) adaptations which enable plants to re-establish in burned areas.

Some examples of the first category are:

a. trees with thick fire-resistant bark.

b. trees with high crown bases.

Some examples of the second category are:

a. underground rhizomes.

b. dormant buds.

c. root suckers.

d. trunk sprouts.

e. light-weight seeds.

f. serotinous cones.

g. heat-resistant seeds.

A more complete look at these adaptations can be found in Clements (1910), Ahlgren and Ahlgren (1960), Hare (1961), Brown and Davis (1973), Lotan (1976), and Lyon and Stickney (1976).

Fire has been an important and sometimes controlling factor affecting plant succession (Vogl 1970). Rowe and Scotter (1973) have discussed the interactions between vegetative successions and wildlife habitat in the boreal forest. Many native mammals and birds have habitat requirements that correspond with niches in many postfire successional stages (Heinselman 1973). Some examples of these mammals and birds are: 1) moose which require a combination of recent burns and adjacent maturing forest; 2) beaver which require stands of deciduous trees near lakes and streams; 3) snowshoe hare which reach population peaks in early postfire stands; 4) white-tailed deer which require small recent burns; 5) many species of small mammals which can survive fires underground and re-invade the burns quickly; 6) ruffed grouse which feed on the buds of aspen in winter; and 7) woodpeckers which seek out insects in snags left after a burn. Insects also may have habitat requirements that correspond with various postfire

successional stages.

These adaptations by plants and animals illustrate that fire has been an important factor in many terrestrial ecosystems over evolutionary time. Fire exclusion would result in restructuring the entire system, and gradually eliminate the niches of many formerly abundant wildlife species (Heinselman 1973).

Some of the large ecosystems in North America in which fire plays an important role are: boreal forest (Lutz 1956, 1960, Komarek 1971, Rowe and Scotter 1973, Viereck 1973, Rowe _et al_. 1974, 1975, Wein 1975, Kelsall _et al_. 1977), northern Rocky Mountains (Habeck and Mutch 1973, Loope and Gruell 1973, Arno 1978a), western U.S. coniferous forests (Cooper 1961, Weaver 1974), Sierra Nevada (Kilgore 1973), northcentral U.S. forests (Wright and Heinselman 1973, Frissell 1973, Heinselman 1973, Ahlgren 1974), northern U.S. coniferous forests in general (Wright and Heinselman 1973), southeastern U.S. coniferous forests (Komarek 1974), desert and desert grasslands in North America (Humphrey 1974), chaparral in southwestern U.S. (Biswell 1974, Mooney and Conrad 1977), and grasslands in North America (Daubenmire 1968, Vogl 1974).

According to Wright and Heinselman (1973), the role of fire in North American ecosystems includes the following:

1. Fire as an influence on the physical-chemical environment.
2. Fire as a regulator of dry-matter accumulation.
3. Fire as a controller of plant species and

communities.

4. Fire as the determinant of wildlife habitat patterns and populations.

5. Fire as controller of forest insects, parasites, and fungi.

6. Fire as the controller of major ecosystem processes and characteristics (i.e. nutrient cycles and energy flow, succession and diversity).

The "fire regime" of a fire-dependent ecosystem helps describe the role fire plays. The "fire regime" (Heinselman 1975) consists of the following:

1. Mean fire-free interval (average number of years between fire years) for habitat types.

2. Maximum and minimum fire-free interval for habitat types.

3. Characteristic fire behavior.

4. Characteristic fire size.

5. Interactions between climatic variations and fire occurrence.

6. Relationship between fire and cultural history of the area.

7. Fire effects or impacts.

B. Fire History Studies

Fire history studies have tried to describe the natural "fire regime" for many forest ecosystems. Some of the fire history studies which were done in northern and central Canada and in northcentral United States are: boreal forest (Rowe et al. 1974, 1975, Johnson and Rowe 1975, Wein 1975), Algonquin National Park, Ontario (Cwynar 1975, 1977), Pukaskwa National Park, Ontario (Alexander 1977),

northeastern Minnesota (Heinselman 1973), northcentral Minnesota (Frissell 1973), and northern Minnesota (Swain 1973).

Fire history studies have also been carried out in the western United States. Some of these were done in: Sierra conifer forests (Kilgore 1973, McBride and Laven 1976, Parsons 1976), Lava Beds National Monument in northern California (Johnson and Smathers 1976), Oregon (Weaver 1959, Soeriaatmadja 1966), Pacific Northwest (Martin et al. 1976), Cascade Mountains of Washington (Fahnestock 1976, 1977, Woodard 1977), and southwestern Idaho (Burkhardt and Tisdale 1976).

Fire history information is available for some forest ecosystems in the northern U.S. Rocky Mountains. Some of these studies were done in: Estes Park in Colorado (Clements 1910), Rocky Mountain National Park (Clagg 1975), Jackson Hole area of northwest Wyoming (Loope and Gruell 1973), Yellowstone National Park (Houston 1973), Selway-Bitterroot Wilderness of Idaho and Montana (Habeck 1972), Danaher drainage of the Bob Marshall Wilderness Area, Montana (Gabriel 1976), Bitterroot Mountains, Montana (Arno 1976, 1978a), Swan Valley, Montana (Antos 1977), and Coram Experimental Forest, Montana (Sneck 1977).

Some fire history information is available for forest ecosystems in the Canadian Rocky Mountains. These studies were done in: Waterton Lakes National Park, Alberta (Mackenzie 1973), Banff National Park (Byrne 1968), and

Jasper National Park (Heinselman 1975, Tande 1975, 1977). Only the fire history study in Jasper National Park used a fire-scar analysis to document the fire history. Mackenzie (1973) used age-class data and Byrne (1968) used historical records to describe the role of fire in each of their study areas.

Methods for determining the fire history of an area were first described by Clements (1910). Recent fire history studies have used a combination of age-class analysis, fire-scar analysis, historical records and fire agency records to document fire history. Tande (1977) and Arno and Sneck (1977) have proposed methods which use all of these techniques to determine the historic fire record. After the "fire regime" of an area is determined, it is used as a base for interpreting the influence of past fires on the vegetation of the study area. (Tande 1977).

C. Fuel Appraisal and Fire Management Possibilities

Current fire management philosophy recognizes that fire is not just a recent aberration that the white man has introduced to the environment, but that it has been a natural part of our forest and rangeland ecosystem (Stankey 1976). In fire management planning it is possible to reintroduce the beneficial aspects of fire into the forest and range environment while still protecting values at risk. The key element in the fire management program is the land management objective; fire is useful and beneficial only

when it helps achieve some specific purpose (Stankey 1976). The fire management program for a park or wilderness area must consider resource value in adjacent areas (i.e. values at risk).

Ecologists have traditionally taken a biological and compositional approach, examining the effects of burning on populations and communities, while foresters have been more aware of the structural importance of biomass as fuel (Rowe and Scotter 1973). Fire should be understood in the context of the structure of ecosystems, in which the geometrical relationships of the components are fully as important as their composition (Rowe and Scotter 1973). The beneficial use of fire requires a thorough knowledge of fire behavior, suppression principles and procedures, and fire effects (Robinson 1970).

Knowledge of fuel loading and distribution in wildland fuel complexes has long been recognized as an important requirement for predicting fire behavior (Muraro 1971). Some methods for predicting potential fire behavior of fuels (Albini 1976) require estimates of loading (weight per unit area) (Brown and Marsden 1976). Most research in fuel loading has been directed towards the development of regressions to predict fuel loading of the vegetative complex in various forest types based on plant parameters (e.g. diameter at breast height for trees). Kittredge (1944) estimated foliage weight from tree diameter. La Mois (1958), Fahnestock (1960), Kiil (1967, 1968), Brown (1970), Muraro

(1971), Sando and Wick (1972), Roussopoulos and Johnson (1973), Woodard (1974), Walker and Stocks (1975), Brown (1976a, 1976b), Brown and Marsden (1976), Gary (1976), Brown et al. (1977), Johansen and McNab (1977) and Brown (1978) examined various components of the fuel complex to develop fuel loading regressions. Recently Kiil (1968) and Muraro (1971) have examined the entire fuel complex and have predicted fuel loading from stand parameters with varying success.

Fuel classification in North America originally was based on estimates by experienced observers of the fuel complex (Kiil 1968). An example is Hornby's (1935) division of forest regions "into units according to their characteristics respecting fire spread and difficulty of establishing and holding fire control lines" called fuel types. More recently photographic manuals for identifying fuel types by regions have been produced which also provide relative values for rate of spread and resistance to control. Fahnestock (1970) has developed a dichotomous key which establishes "the framework for a permanent, universal fuel appraisal system". The key is based on an objective observation of specific fuel characteristics. Grigel et al. (1971) and Kiil et al. (1973) constructed fire hazard classifications for Waterton Lakes National Park and Prince Albert National Park, respectively. Fuel descriptors such as forest age, height, crown density, crown form, lesser vegetation, horizontal and vertical distribution of fuels,

moisture regime, and seasonal variation in fuel conditions were related to probable differences in fire behavior, and formed the basis for a breakdown of forest cover types into nine major fuel types (Kiil et al. 1973).

Fuel classification does not provide a quantitative measure of the amount or importance of each fuel variable in relation to fire behavior (Kiil 1968). Anderson (1974) emphasized the need to incorporate fuel quantity and distribution sampling as part of the resource inventory for an area. Brown (1974) developed a sampling procedure for dead vegetative material which was found to be compatible with timber and range inventories (i.e. line-intersect method). Fuel loading regressions (single tree or stand parameters) which incorporate timber inventory data can provide an estimate of live vegetative fuel loading within a stand (Anderson 1974). This fuel loading information can be used as input parameters for a mathematical fire spread model (e.g. Rothermel 1972) to predict various fire potentials of a vegetation type (e.g. rate of spread, fire intensity, and crowning potential).

Sampling for these fuel input parameters has been found to be costly, time consuming and tedious (Rothermel 1972). Fuel models were first introduced in the 1972 United States National Fire-Danger Rating System and provided a means of organizing fuels data for input into Rothermel's mathematical fire spread model (Deeming et al. 1978). These fuel models permitted the application of fuel sampling

results on a regional basis.

Another important consideration in the fuel appraisal system is determining resistance to control of fuel types (Anderson 1974). A system for rating fuel complexes in terms of resistance to control for handtools was developed by Murphy and Quintilio (1978). Fuel types were described in terms of the four major fuel components of trees, shrubs, surface litter, and duff. This approach suggests possibilities of developing a simple framework within which to develop indicators of fuel loading and flammability incorporating the systems discussed previously.

Fire managers of United States National Parks and Forests have developed several land management plans which include fire considerations. Fire-related activities or prescriptions to support land management objectives were also developed (Davis 1978). Barney (1975) defined fire management as "the integrating of fire-related biological, ecological, physical, and technological information into land management to meet desired objectives." Mutch (1976) emphasized that "fire management still consists of presuppression (including prevention and fuels management), suppression, postsuppression rehabilitation, and prescribed fire", but the pervasive new twist was that the land use plan called for the right "mix" of these components to meet specific objectives rather than a rigid application of fire control effort.

Therefore, the development of the resource management

plan for Kananaskis Provincial Park requires a thorough consideration of fire history and fuel appraisal information. The approaches and techniques outlined in this literature review were used as a basis for collection and analysis of the fire history and fuel appraisal data. This information can be used in the development of fire-related activities and prescriptions to support land management objectives proposed for Kananaskis Provincial Park.

III. THE RESEARCH AREA

A. Location

The research area is located approximately 120 kilometres southwest of Calgary, Alberta at the head of the Kananaskis Valley. The area includes the main valley around the Lower and Upper Kananaskis Lakes up to the Opal Range on the east, the Upper Kananaskis River and Three Isle Creek drainage, the Smith-Dorrien Creek drainage, and the area around the Burstall Lakes (Figure 1). It lies at 50° 37' north latitude, 115° 7' west longitude.

Kananaskis Provincial Park in which this study was conducted encompasses 508 sq. kilometres. This includes approximately 236 sq. kilometres of forest. Elevation of the forested lands ranges from 1525 metres at the valley bottom to 2300 metres, the approximate treeline. The highest mountains in the Park reach an elevation of 2700 to 3200 metres.

B. Forest Classification

The research area is classified as the SA. 1 (East Slope Rockies) Forest Section of Rowe's (1972) Subalpine Forest Region. Two locations (King Creek and Upper Lake) in the research area have some Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco var. *glauca* (Beissn.) Franco) and, therefore, may be classified in the M 5 Forest Section of Rowe's (1972) Montane Forest Region. Kondla (1978) showed

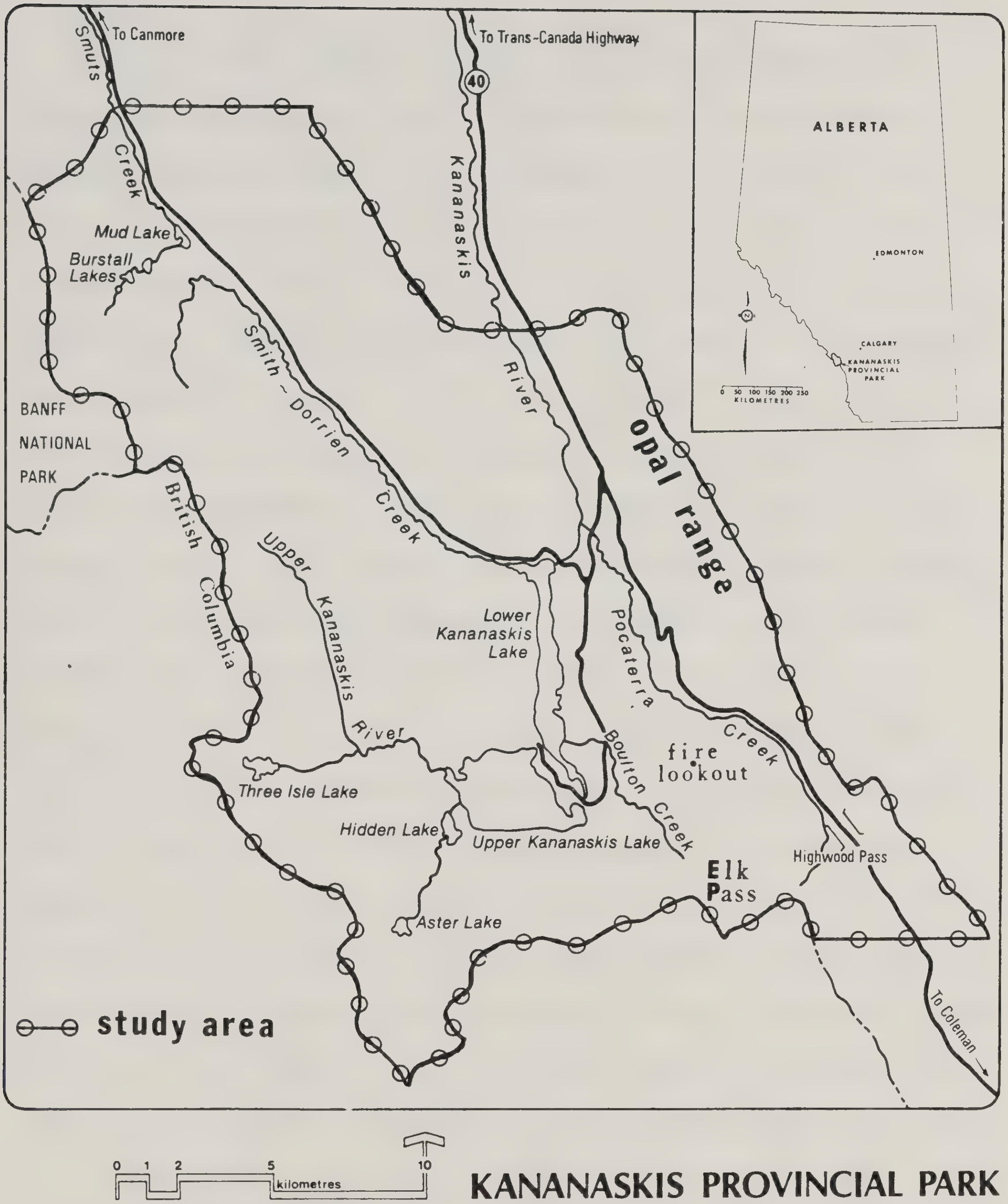

Figure 1. Location of study area.

the specific location of these Douglas-fir stands.

C. Climate

Year-round weather records are not available for Kananaskis Provincial Park. Summer (June to September) records are available for Kananaskis Fire Lookout (elev. 2072 m), operated by the Alberta Forest Service for the period 1966 to 1975. Figure 2 illustrates the monthly mean temperature and precipitation for the summer at Kananaskis Fire Lookout. Jaques (1977) indicated that the climate within the Park represents a fairly narrow range of the total Rocky Mountain east slopes climatic regime, being skewed towards the moist-cool end of the gradient. Jaques (1977) also indicated that on a few steep south-facing slopes in the Park, the climate was intermediate to the dry-warm end of the east slopes climatic gradient. These drier areas are currently occupied by Douglas-fir. Powell and MacIver (1977) used a factor analysis procedure and found that the summer climate of the upper Kananaskis Valley and a few areas south formed a macroclimatic group based on statistically significant variables between climatic groups such as temperature, precipitation, water deficiency and number of days with minimum temperature greater than -2.2°C.

Some of the extremes in climate that Kananaskis Provincial Park has experienced in the period 1966-1975 are:

1. Highest maximum temperature in July or August was 35°C on July 9, 1966.

2. Lowest minimum temperature in July or August was

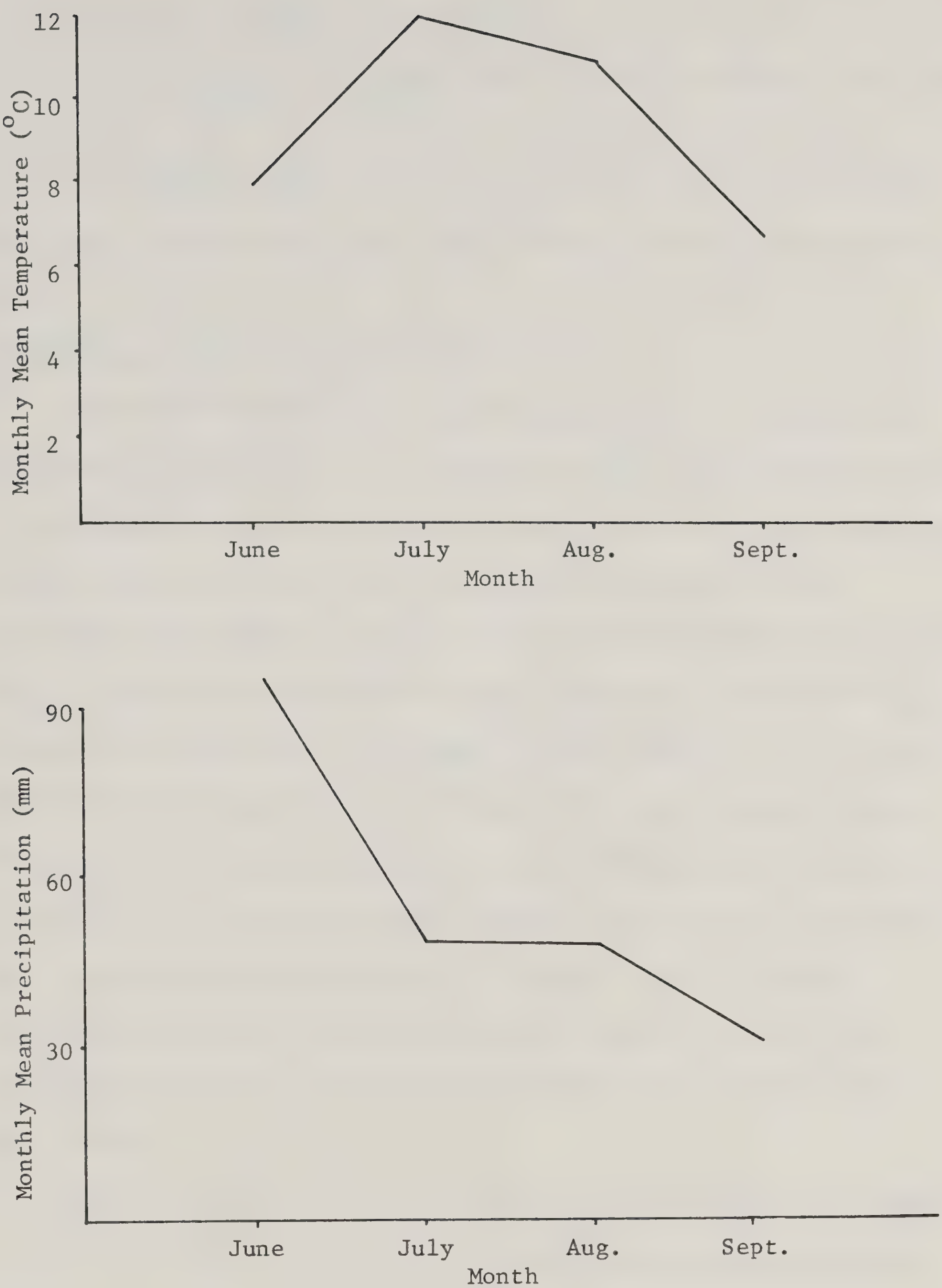

Figure 2. Monthly mean temperature and precipitation for the summer at Kananaskis Fire Lookout (based on data for the period 1966-1975).

-6°C on August 26, 1967.

3. Lowest relative humidity in July or August was 14% on August 25, 1969.

4. Longest period without precipitation was 26 days in August, 1969.

Snow can occur during any month of the year in Kananaskis.

D. Geology, Geomcrphology and Soils

Bedrock of Kananaskis Provincial Park is primarily composed of clastics and carbonates from the Middle Devonian to the Lower Cretaceous Periods about 100 million years old. Ridges, cliffs, and peaks are composed primarily of Paleozoic limestones and dolomites. The valley bottoms and lower slopes are composed of less resistant Mesozoic era shales and sandstone. Two major thrust faults and a series of folds have resulted in the Elk and Opal Ranges (Lewis thrust) and the Spray Mountains (Bourgeau thrust). The most recent glaciation (Wisconsin) ended 9,000 to 10,000 years ago. Ice glaciers descended the Smith-Dorrien, Upper Kananaskis and Three Isle drainages and moved down the Kananaskis valley to the Bow River (Milus, Tress, Baron, Ltd. 1977).

Glacial debris overlays much of the bedrock. A veneer of glacial till was left by the melting of stagnant ice. Hummocky moraine and eskers are common in the Park area. Small ponds, lakes and wetlands occur in ice marginal channels which formed in the till adjacent to the melting ice (Milus, Tress, Baron, Ltd. 1977).

Luvisols are present on older glacial deposits, most commonly found on till and gravel surficial materials around the Kananaskis Lakes. Brunisols are common at higher elevations where soil development is slower. Regosols are found on recent colluvial, alluvial, and glacio-fluvial deposits. Gleysols are found in areas of groundwater discharge, high water table, and in undrained depressions. Some organic soils exist in areas of organic deposits on poorly drained sites (Milus, Tress, Baron, Ltd. 1977).

E. Vegetation

The vegetation of Kananaskis Provincial Park is classified in the subalpine ecological zone according to the ecosystem classification described in Walker *et al.* (1978). The ecosystem classification is based primarily on differences in vegetation physiognomy which reflect macroclimate (Walker *et al.* 1978). This zone is divided into upper and lower subalpine subzones based on differences in vegetation physiognomy and the occurrence of certain vegetation types.

Walker *et al.* (1978) described the lower subalpine subzone as a closed forest (distance between crowns is less than 2 times crown width) which occurs generally below 2000 metres elevation. The upper boundary occurs at 2100 and 1850 metres on south and north aspects, respectively.

Mature Engelmann-white spruce hybrid (*Picea engelmannii* Parry x *P. glauca* (Moench) Voss.) - subalpine fir (*Abies*

lasiocarpa (Hook.) Nutt.) forests occur in the higher elevational areas of the lower subalpine subzone. The Engelmann-white spruce hybrid in the Park is called Engelmann spruce in the rest of this thesis. Common vegetation types in these mature forests were described by Kondla (1978) for Kananaskis Provincial Park. These were Engelmann spruce - subalpine fir/grouseberry(*Vaccinium scoparium* Leiberg)-feathermoss (common mosses in Kananaskis-*Pleurozium schreberi* (Brid.) Mitt., *Mnium* sp., and *Dicranum fuscecens* Smith), Engelmann spruce-subalpine fir/false azalea(*Menziesia ferruginea* Smith)-feathermoss.

Successional lodgepole pine (*Pinus contorta* Loudon var. *latifolia* Engelm.) forests dominate the rest of the lower subalpine subzone. Common vegetation types in these forests were described by Kondla (1978). These were lodgepole pine/grouseberry, lodgepole pine/feathermoss with buffaloberry(*Shepherdia canadensis* (L.) Nutt.), showy aster(*Aster* sp.) and grouseberry common in the understory, and lodgepole pine/false azalea common in the Elk Pass area. Western larch (*Larix occidentalis* Nutt.) occurs in a few locations (Upper Lake, interlake and Elk Pass areas) (Murphy 1960). Douglas-fir and limber pine (*Pinus flexilis* James) occur on rocky, south-facing sites in the Park.

Walker *et al.* (1978) described the upper subalpine subzone as open forests (crowns separated by a distance of 2 to 5 times crown widths) occurring at 2000-3000 metres elevation. This subzone is transitional between the lower

subalpine subzone and the treeless alpine zone.

Engelmann spruce, subalpine fir and alpine larch (*Larix lyallii* Parl.) are common in the upper subalpine subzone. Closed forests are common at the lower elevational areas of the subzone. Common vegetation types in this subzone were described by Kondla (1978). These were Engelmann spruce - alpine larch - subalpine fir/grouseberry, Engelmann spruce - subalpine fir/grouseberry and alpine larch/heather(*Phyllodoce* sp.) - grouseberry. Tree islands are common with heather meadows occurring between them.

F. Cultural History

For at least 8,000 years, man has occupied the Kananaskis Lakes area with most early use concentrated from 5,000 B.C. to 200 A.D. Most of these early people were transient hunters and gatherers, whose camps and tool-making remnants have been located by archaeologists (Aresco, Ltd. 1977).

In the 17th century, the Kootenay, Salish, and Snake Indians roamed the foothills and mountains of southern Alberta. The Snake Indians dominated the Bow River Valley in the mid 18th century but were decimated by a smallpox epidemic in 1780. They were displaced westward by the Peigan Blackfoot (Aresco, Ltd. 1977).

The Stoney Indians moved to the Kootenay Plains and Morley area in the early 1800's. They travelled through the Kananaskis Valley on hunting trips to British Columbia. The

creation of Rocky Mountain Park (now Banff National Park) in 1889 limited the Stoney's hunting and trapping (Aresco, Ltd. 1977).

James Sinclair travelled through the Kananaskis Valley on the way to central B.C. in 1854 with a large party of settlers. In 1858, James Palliser travelled through the Park in late August on his way to B.C. Walter Wilcox and a group of men spent six days at the Kananaskis Lakes in 1901. George Pocaterra trapped, hunted, and prospected with the Stoney Indians from 1906 to 1926.

Elizabeth Rummel visited the Kananaskis Lakes from 1921 to 1932 with relatives and friends from the Millarville area (Elizabeth Rummel, pers. comm. 1978). Bill Paterson travelled through the Kananaskis Lakes area in the 1930's from the Buffalo Head Ranch in the Highwood Valley.

Resource use has not been intensive around the Kananaskis Lakes. In the late 1880's, a sawmill was reported to have operated near the Upper Kananaskis Lake. Some logging took place in the Park until the early 1940's, when damming of the lake prevented the transportation of logs (Aresco, Ltd. 1977). In 1952, logging began in the Smith-Dorrien Valley; 3,700 acres were cut from 1952 to 1978. Logging is no longer permitted within the Park boundaries.

The Kananaskis Lakes area has seen relatively light use by man and has escaped extensive development until the recent construction of the facilities for Kananaskis

Provincial Park. Recreation use was limited until the improvement of the Kananaskis trail to facilitate the construction of the dams in the 1940's at the lakes. Paved access to the Park (completed in 1978) resulted in a marked increase in the number of visitors to the lakes area.

G. Wildlife

The faunal component of Kananaskis Provincial Park is severely constrained by the mountain environment, with narrow valleys rising sharply to barren rock faces or glaciers, harsh climatic conditions, and forests dominated by coniferous vegetation. Kananaskis Provincial Park does support a diversity of provincially rare species, particularly those species confined to the Cordilleran life zone (G. More, pers. comm. 1979). Many wide-ranging mammals and birds use the Park as only part of their required home range. Some of the large mammals in the Park which utilize early-successional forests are mule deer (*Odocoileus hemionus* Rafinesque), white-tail deer (*Odocoileus virginianus* Zimmermann), moose (*Alces alces* Linnaeus), elk (*Cervus elaphus* Linnaeus) and bighorn sheep (*Ovis canadensis* Shaw) (G. More, pers. comm. 1979).

Hunting and trapping is no longer permitted within the Park boundaries. Most range for big game species is outside of the Park boundary; and, therefore, many of these animals are accessible during the regular hunting season. Ungulate populations are low in Kananaskis Provincial Park in

comparison to the other ungulate ranges (G. More, pers. comm. 1979).

H. Fisheries

Fishing is an important activity within the Park; it is largely maintained by an intensive lake stocking program by Alberta Fish and Wildlife (Thompson 1978). Four of the Park's lakes had native populations of fish: Lower Kananaskis Lake, cutthroat trout (*Salmo clarki* Richardson), and Dolly Varden (*Salvelinus malma* Walbaum); Mud Lake, a sparse and seasonal population of cutthroat and Dolly Varden; Central Hogarth Lake, cutthroat; and Upper Hogarth Lake, Dolly Varden and rainbow trout (*Salmo gairdneri* Richardson).

Lawson, Maude, Three Isle, Rawson (formerly Sarrail), and Upper Kananaskis Lakes have been stocked with cutthroat trout and Lower Kananaskis Lake with rainbow trout. Freshwater shrimp have been introduced to the Upper and Lower Lakes to increase the food supply, although their effect on lake productivity is not yet known (Thompson 1978).

IV. METHODS - FIRE HISTORY

A. Field Procedures

Photo Interpretation

Aerial photographs were interpreted[1] before going into the field to map obvious fire boundaries and vegetation type changes, to identify all access routes such as roads, trails and powerlines, and to lay out a field reconnaissance. The 1950 series of aerial photographs was useful for mapping major fire boundaries and vegetation type changes. The 1976 photo series was useful in identifying access routes such as roads, trails, cutlines and powerlines which were not present in the 1950 photos. Detail was transferred from 1950 photos to the 1976 photos using a transfer-scope at the Remote Sensing Centre.

Field Reconnaissance

During the field reconnaissance, an initial examination of forest types and the amount of fire scar information that was available in the Park was made. Preliminary observations were made on the following:

1. Differences in stand composition and age-class were noted and checked with aerial photos and Alberta forest cover type maps.
2. All fire-scarred trees to be sampled later were noted on field forms, and the following data recorded:

    a. sample point number, dominant understory shrubs

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[1] Photo interpretation was carried out in Edmonton at the Alberta Centre for Remote Sensing.

and herbs, scarred-tree number

b. species

c. diameter at breast height (1.4 metres)

d. maximum height of each fire scar

e. number of externally visible scars

f. elevation

g. aspect

h. remarks, such as descriptive location and recommendation for sampling

Other characteristics were noted when the tree was sampled during the later fire history study. Approximately one week was spent conducting the reconnaissance of the research area.

Sampling Fire-Scarred Trees

Sample points for the fire history study were established along the stand edge and within remnant stands. The number of sample points was varied depending on the complexity of fire history and availability of fire-scarred trees. If fire-scarred trees were not available, age-class of regeneration (lodgepole pine if available) was determined by increment cores taken at a height of 30 cm. If regeneration was present which was not indicated by a fire-scar date (low intensity fires sometimes stimulate regeneration without scarring any trees), increment cores were taken near the fire-scarred tree. This was not common in Kananaskis Provincial Park.

The cross sections taken from fire-scarred trees and increment cores were aged in the field to obtain a

preliminary picture of fire history. If the fire history was not clear from one cross section then additional cross sections were cut and aged until the fire history was clear.

Trees which fit the following requirements had the highest priority for sampling:

1. Trees with the greatest number of externally visible, individual fire scars.

2. Trees with no apparent rot.

3. Trees which were not near trails, roads, or were not a unique feature of the Park (as requested by Parks for aesthetic reasons).

At each fire-scarred tree the following data were collected:

1. The information listed previously in the field reconnaissance under point 2.

2. A photograph was taken of the fire-scarred tree(s) and the site.

3. The number of cross sectional scars, and photograph number.

In addition, the precise location of the sample tree was marked on the appropriate aerial photo and transferred later to a topographic map, and cross sections were aged and appropriate increment cores taken.

B. Analysis of Data

Preparing the Cross Sections

The cross sections were laid out to dry in a heated building or in the sun after each day's sampling. After the cross sections were dry (1-2 weeks), they were sanded to make the annual rings more distinct. Fine steel wool was

used to finish if a microscope was required to assist in ring counts.

Ring Counts

A variable-power binocular microscope was used to obtain accurate ring counts. Rings on cross sections and cores were counted inward from the cambium. The method used to age fire scars is described by Tande (1977) and Arno and Sneck (1977).

Correlating the Fire Chronologies

Ring counts from each individual tree may not be entirely accurate due to occasional missing rings, false rings, pockets of obscured rings, or rot (Arno and Sneck 1977). These may cause minor errors in estimating fire years. To help minimize these errors, a "master fire chronology" was developed by combining fire-scar records from all individual trees. The fire-scar years taken from the cross sections which were accurate were marked with an X. The fire scar years which were thought to be incorrect were marked with a dot. The fire years were then compared on a vertical column of years from the oldest fire scar date to 1977 placed on graph paper. The dots were then adjusted to correspond tc the correct fire year. A more detailed explanation of this procedure can be found in Arno and Sneck (1977).

A fire chronology of Kananaskis Provincial Park was developed from fire-scarred tree wedges, age-class data and Alberta Forest Service records. A total of 142 fire scars

and 705 increment cores were taken on 117 fire history plots to establish the fire chronology.

Fire scar dates were determined by aging fire-scarred tree wedges from lodgepole pine, alpine larch, Engelmann spruce, subalpine fir and Douglas-fir. It was difficult to date stand disturbances with many alpine larch, Engelmann spruce and subalpine fir because of trunk rot. Remnants of older stands that were left on the edge or within past fires provided the best source of fire history information.

Analyzing Age Classes

Several small trees were felled to determine an age-height correction factor for each tree species. Sections were cut at 30 cm and ground level to determine age correction to reach 30 cm. The age corrections used were 3 years for lodgepole pine, 4 years for spruce,and subalpine fir. The age correction used for spruce, subalpine fir and alpine larch at high elevation varied from 10 to 25 years depending on the boring height, which changed due to trunk rot.

Total ages of trees from each sample plot were listed in chronological order. The total age was determined by adding the correction factor to the increment core ring count. The increment-boring data were augmented by including the total age of cross-sectioned, fire-scarred trees with the sample from the nearest plot.

Once the tentative age classes were determined, based on the oldest tree in each class, comparisons of the

age-class data and the fire scar chronology were made. From these comparisons, the role of fire in age-class structure of forests was determined. A more detailed explanation of the correlation procedure can be found in Arno and Sneck (1977).

Stand Origin Map

The stand origin map was constructed by utilizing the age-class data and fire scar chronology information to determine age-class boundaries. Many stands which contained fire history information were a hectare or less in size, perhaps because of the high intensity of past fires. Some of these stands are included in the stand origin map. In stands with no direct fire history information (i.e. fire scars or lodgepole pine regeneration), the oldest spruce aged is used to estimate the date of stand origin. Alpine larch was used instead of spruce if present in the stand because of larch's probable pioneer status in succession at high elevation (as indicated by a comparison of ages among species within a stand).

Snags provided a secondary source of information which extended the fire chronology back before fire scars on living trees. Data were collected from both standing snags and those lying on the forest floor. Four problems were encountered when snags were used to obtain fire history data. These were:

1. Weathering of the tree's exterior caused fire dates to be incorrect up to 10 years.

2. Determining which fire killed the snag was sometimes difficult; cross-dating to other living and dead fire scar information was necessary.
3. Sometimes the snag died a number of years after a fire scorched its crown.
4. Trunk rot added to aging problems.

The large expanse of young, even-aged stands in Kananaskis Provincial Park made it necessary to use snags if historic fire years were to be determined.

Stand origin dates for some stands were extrapolated from nearby stands that were sampled. This was done more in the inaccessible areas of the Park than in the main Kananaskis Valley. This is best illustrated by examining the distribution of fire history plots presented in Figure 3. More fire history plots were located in the main valley because there was much more fire history information than at higher elevations.

Fire Year Maps

Fire-year maps were constructed for Kananaskis Provincial Park depicting fires that burned between 1712 and 1978.

Fire history information from sample plots for each fire was examined to determine its areal extent. Recent fires in the Park have destroyed evidence of previous fires such that much extrapolation was needed in mapping early fires. Extrapolations were based on burn directions, slope, aspect and a knowledge of fire behavior. Cross-hatching was

used in mapping fires to indicate the subjective placement of fire boundaries.

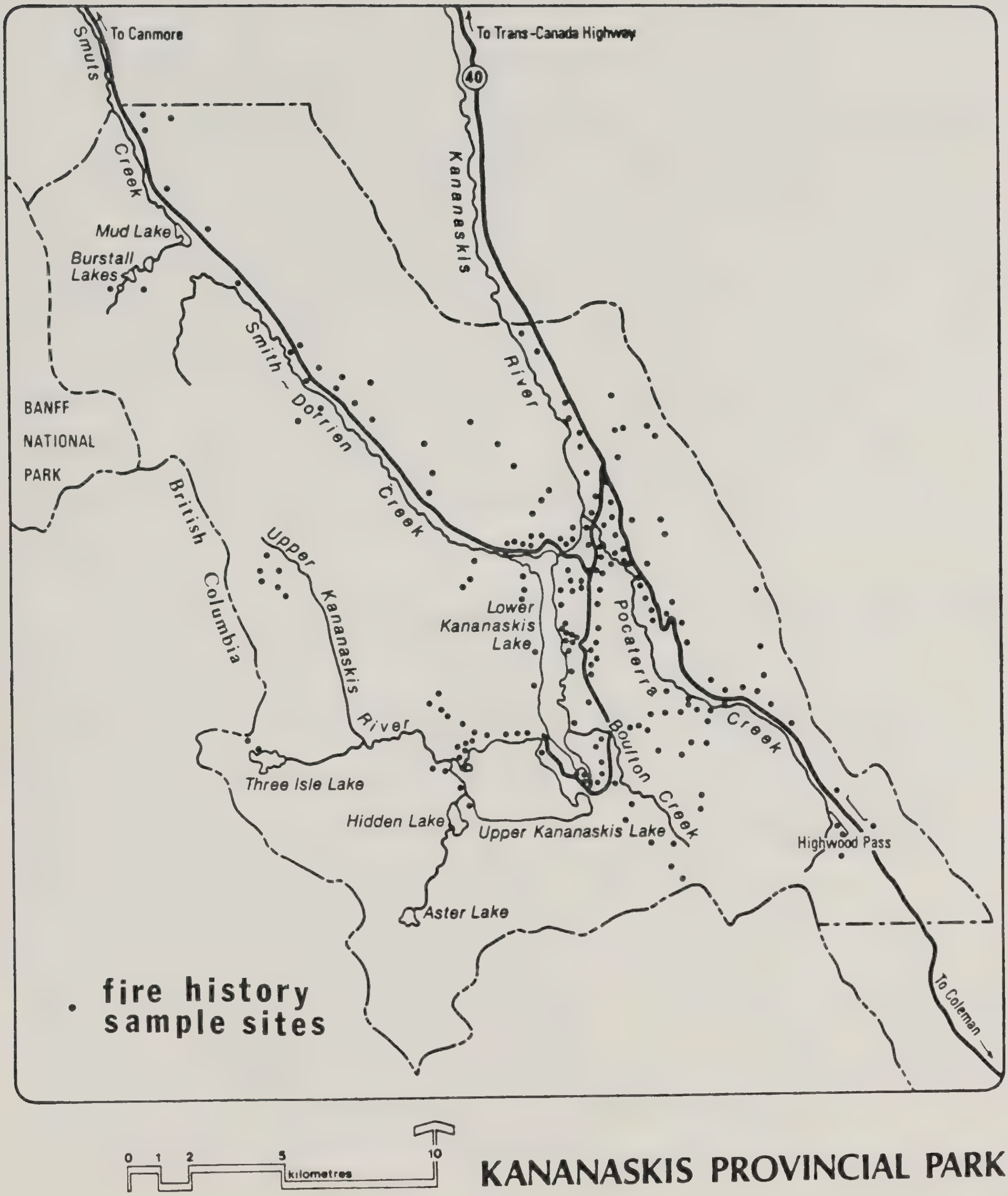

Figure 3. Location of fire history sample sites.

V. METHODS - FUEL APPRAISAL

A. Fuel Type Map Construction

Fuel types were stratified on the basis of differences in stand crown density, age, plant species composition, amount of dead and down material, presence of ladder fuels and development of the shrub layer. Thirteen fuel types were identified in the field, of which eight were sampled in 1977 and three in 1978 (See Table 5 for fuel type descriptions). Two fuel types - clearcuts and partial cuts, were not sampled because they were assessed by Culler and Maloney (1977).

Stand boundaries distinguished on the stand origin map and field notes on stand characteristics were used to establish fuel type boundaries. A light table was used to transfer detail from the stand origin map to the fuel type map. Clearcuts and partial cut areas in the Smith-Dorrien Valley were delinated on the fuel type map using a map-o-graph and a larger scale map from Culler and Maloney (1977). The final fuel type map was originally drafted at a scale of 1:21,120 but later reduced for the thesis (See Figures 22-25 and Appendix 6, attached pocket).

B. Fuel Loading - Field Procedures and Data Analysis

Aerial Fuels

Sample points (Basal Area Factor: 40 for fuel type 2 and 20 for the other fuel types because of differences in tree density) were established to determine tree species density (trees/ha) for each fuel type using a variable radius plot cruising procedure (Dilworth and Bell 1973). Twenty sample points were established in fuel type 1. The number of sample points was reduced to fifteen for fuel type 1A - 10 because of time constraints on field work.

At each sample point, normally one tree was measured for total height, crown length and crown width for each tree species. Linear regressions were later calculated for spruce and pine relating diameter at breast height to crown width. This was done for each fuel type and all fuel types combined. A single regression for spruce was used in aerial fuel calculations, because a multiple comparison of the regression slopes for each fuel type showed no significant difference (95% probability level). A single regression for pine was used because of the results of the same test. A single regression for subalpine fir was used because of the low number of observations. Regression equations and multiple comparison results are presented in Appendix 3.

An estimate of crown biomass (tonnes/hectare) was obtained for each fuel type by the following method:

1. A crown biomass estimate was calculated for each sample point:

    a. Using single tree regressions (spruce and

lodgepole pine input parameters - crown width and DBH (Kiil 1967), subalpine fir and alpine larch input parameters - crown ratio 10(crown length/total tree height) and DBH (Brown 1976b)) an estimate of crown biomass for each tree in the plot was obtained. Brown's (1976) regression for western larch was used for alpine larch.

b. A crown biomass (tonnes/hectare) estimate for individual trees was obtained by multiplying the estimate of crown biomass for each tree and the number of trees per hectare that tree represents (i.e. as indicated by the stand table factor).

c. All crown biomass estimates for individual trees were summed for the plot.

2. The crown biomass estimates were averaged for all sample points in each fuel type.

Organic Layers

At each sample point, two depth measurements of the organic layers were taken on each line-intersect transect at a distance of .31 and .91 metres from the plot centre. A total of 60 depth measurements were taken for each fuel type (80 for fuel type 1 and none for fuel type 8).

A regression of the form lny = a + bx[1] was run with humus data obtained from Muraro (1971). This regression (ln y = -.6971 + .2108 x, Residual Mean Sq. = .0105) was used to obtain humus biomass estimates (tonnes/hectare) for each depth measurement. A biomass estimate for each fuel type was obtained by averaging the biomass estimates for each depth measurement.

Herbs and Shrubs

In each fuel type 15 plots were sampled for herbs and shrubs with a 1x1/2 metre clipping frame (20 plots in fuel

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[1] ln = common log y =biomass(lb/ft^2) x = depth(in.)

type 1). The frame was placed at a distance of 1 metre from the plot centre, with the direction randomly determined using the second hand of a watch. All above-ground portions of plants were put into bags for drying (70°C for 24 hours) and weighing. Herb and shrub biomass estimates were not separated into species. Notes were taken on overall height of shrub layer (metres) and shrub density (A, B, or C see Murphy and Quintilio 1978).

Dead and Down

Estimates of dead and down material were obtained by Brown's (1974) line-intersect method using 15.2 or 30.5 metre long lines depending on the quantity of dead and down material. Two line-intersect transects were taken at each sample point. The direction of the transects was randomly determined by using the second hand of a watch. Three fuel depths were taken on each line transect for a total of 90 for each fuel type (120 for fuel type 1). Fine fuel loading was separated into three size classes ($>0\geq.64$ cm,$>.64\geq2.5$ cm and $>2.5\geq7.6$ cm) according to Brown (1974). Course (>7.6 cm) dead and down loading was separated into sound and rotten categories according to Brown (1974).

Moss

One moss depth measurement was taken at each sample point along with a cover estimate. Kiil (1968) provides a weight per acre-inch value (1.75 tons per acre inch) for moss which was used to obtain individual moss biomass estimates for each plot. This was done by multiplying the

depth, percent cover and moss weight per acre-inch value (tons/acre inch). The moss biomass estimates for each plot were averaged to obtain the estimate for each fuel type. This estimate was then converted to metric units.

C. Crowning Potential

An estimate of crowning potential on a relative scale was obtained by using a key developed by Fahnestock (1970). This was done at each sample point for a total of 15 for each fuel type (20 for fuel type 1).

The crowning potential key identifies fuel characteristics that lead to crown fires in the canopy and subcanopy, according to the commonly accepted definition of crowning, i.e., "Fire advancing from crown to crown ..." (Fahnestock 1970). The key is based only on essential attributes of the crowns themselves; the user must consider the following additional factors to estimate whether crowning is likely to occur in any given situation:

1. Factors conducive to rapid spread and high intensity of fire in lower fuels - e.g., drought, large accumulations of fuel - also aid crowning but are not prerequisite to it.
2. Wind or upslope movement which is necessary for continuous spread through crowns.

The key ranks crowning potential by increasing ordinal numbers from 0 to 10 and is based on observations and deductions by Fahnestock (1970).

D. Resistance to Control Using Handtools

An estimate of resistance to control using handtools for each fuel type was obtained using keys developed by Murphy and Quintilio (1978). The key uses estimates of tree density and height class, brush density and height class, blowdown or slash, and trenching depth to determine an overall resistance to control estimate, expressed in metres of fire line constructed per man per 45 minute - hour. The resistance to control estimate for each sample point was averaged to obtain the estimate for each fuel type.

E. Statistical Analysis of Fuel Appraisal Data

Fuel loading, crowning potential and resistance to control data were subjected to analyses of variance (one-way) at the 95% probability level. Scheffe's multiple comparison tests (Scheffe 1959) were used to compare differences among means, because more confidence could be placed on differences with this conservative test. The multiple comparisons were carried out at the 95% probability level. All ANOVA tables are presented in Appendix 3.

F. Lightning and Man-Caused Risk and Fire Weather

Estimates of fire occurrence and cause were obtained by a search of Alberta Forest Service fire records for the period 1932-1978. Fire weather index distributions were calculated from Kananaskis Fire Lookout weather records for the period 1970-1977.

G. Fire Hazard Ratings

Fire hazard has been defined in many ways. Anderson (1974) described fire hazard as the various fire potentials of a site. The following fire potentials were considered in describing the fire hazard of fuel types in Kananaskis Provincial Park:

1. The initial rate of fire spread estimated by differences in the amount of fine dead and down material (≤2.5 cm).

2. Fire intensity[1] estimated by differences in the available[2] dead and down fuel loading (all size classes).

3. Crowning potential estimated from Fahnestock's (1970) keys.

The effect of wind, fuel moisture and slope on initial rate of spread were not considered but are discussed in the discussion section. This was done to simplify the ratings. The most desirable way of predicting fire behavior potential of fuels would be a mathematical model which would incorporate differences in fuel loading, wind, slope and fuel moisture. Rothermel (1972) has developed such a fire spread model which has been used in the U.S. Forest Service fire danger ratings (Deeming *et al*. 1978). Fire spread model runs incorporating the fuel data in this study were beyond the scope of this thesis.

Initial rate of spread differences were estimated for

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[1] Byram's fireline intensity was used which is a measure of the heat released per unit of time for each unit of length of fire edge (KW/m) (Albini 1976).

[2] Available fuel was estimated from fuel consumption data of Quintilio *et al*. (1977).

surface fires. The <2.5 cm size class for fine fuels was used to estimate differences in rate of spread because in most cases this size class has been found to supply the energy that characterizes propagation of the spreading flame front (Brown 1972 and Dennis Quintilio, pers. comm. 1978). Classes of low, moderate and high were used to indicate relative differences in initial rate of spread. Actual rates in metres/min. are not provided, because fire spread models were not used and insufficient data were available for Alberta fuel types to predict rate of spread from fine fuel loading differences.

The effects of wind, fuel moisture and slope on fire intensity were not considered as discussed for initial rate of spread. The fireline intensity figure (Byram's intensity described in Albini (1976)) was used because it is concerned with fuels consumed in the fire front where most fire fighting activities will be taking place.

Fire intensity differences were estimated for surface fires. Available dead and down loading was estimated using the following average consumption rates from Quintilio *et al.* (1977): 56% of fuels ≤7.6 cm and 47% of fuels >7.6 cm. These represent the consumption rates found for burns under high Buildup Index conditions and fuel stick moisture content between 9 and 13% at Darwin Lake, Alberta. Available dead and down loading was used to estimate differences in fire intensity because the available portion of this fuel component is a major contribution to fireline energy release

(A.D. Kiil, pers. comm. 1978). The "availability" of the dead and down loading will change with differences in fuel moisture content. Classes of low, moderate and high were used to indicate relative differences in fire intensity. Determination of actual fire intensities (KW/m) was beyond the scope of this study.

H. Overall Fire Hazard

Fuel types were rated separately for initial rate of spread, fire intensity and crowning potential. Each fire hazard rating was divided into three classes of low, moderate and high. The overall fire hazard rating for each fuel type is the highest class of all the individual ratings, with a subscript to indicate which rating(s) was used.

VI. RESULTS - FIRE HISTORY

A. The Fire Chronology 1586 - 1978

A fire chronology of Kananaskis Provincial Park was developed for the period 1586 - 1978. The dates of the 20 fires identified are presented in Table 1. The oldest lodgepole pine found was 390 years old and the oldest Engelmann spruce was 545 years old. Exact fire dates could not be determined prior to 1712, because lodgepole pine regeneration could not be cross-dated with fire scar information. Fire dates before 1712 were estimated using the oldest lodgepole pine of an age class. Fire dates before 1712 derived by this method were 1685, 1658 and 1586. The areal extent of these fires could not be determined because of the destruction of these stands by more recent fires.

Major fires (>1000 hectares; for this study) occurred during 1920, 1904, 1890, 1858, 1840, 1803, 1765, 1743, 1732, 1728 and 1712, with fire intervals[1] that ranged between 11 and 38 years. These fires accounted for 96% of the total area burned from 1712 to 1978. Another major fire in the Kananaskis Valley in 1936 burned approximately 7290 ha north of Kananaskis Provincial Park (Galatea Fire, August 3 - 10, 1936). A fire in the Elk River Valley in British Columbia burned 32,117 ha from June 14 to August 14, 1936. This fire spotted into the Highwood Valley in Alberta on July 23

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[1] Fire intervals are intervals between fires for the entire study area.

Table 1. Fire-scar dates, interval between fires, number of fire scars and size of fires for Kananaskis Provincial Park.

Year of Fire	Interval Since Last Fire (Years) in Park	No. of Fire Scars	Estimated Fire Size Within Park (ha)
1973	6	AFS Records	49
1967	34	AFS Records	233
1933	13	AFS Records	113
1920	16	69	4589
1904	14	6	4597
1890	4	20	3440
1886	6	3	64
1880	22	3	127
1858	6	10	9017
1852	12	3	265
1840	2	3	1557
1838	6	3	86
1832	29	2	299
1803	29	1	3977
1774	9	2	914
1765	22	2	3289
1743	11	1	2578
1732	4	2	5291
1728	16	2	1910
1712		10	9132
		Total 142	

because of gale-force winds and burned 24,519 ha. This fire was out by November 1, 1936. There was no evidence of a 1936 fire within the boundaries of Kananaskis Provincial Park.

Small fires have occurred between some major fires (e.g. 1858, 1840, 1803) but were not found in the periods 1890-1920 and 1712-1765. Small fires in the period 1712-1765 might have been missed because more recent fires have destroyed fire evidence. This explanation may also hold for the period 1890-1920.

Fire chronologies are presented separately for the Smith-Dorrien, Upper Kananaskis, Pocaterra and Lower Kananaskis Valleys in Table 2. The Smith-Dorrien, Upper Kananaskis and Pocaterra Valleys have each had six fires in the period 1712-1978 of which 5, 4 and 5 were major ones, respectively. The Lower Kananaskis Valley has had over twice the number of fires (14) than the other valleys. Ten of these 14 fires were major ones.

B. Stand Origin Map

The stand origin map (Figures 4 to 7 and Appendix 5, attached pocket) illustrates the mosaic of age classes that exist in the Park as a result of past fires. The symbols adjacent to the stand origin dates on the map key provide more detailed fire history information. The symbols define what type of fire scar information was present, the species used to determine the stand origin and whether the stand origin was cross-dated to fire scars in an adjacent

Table 2. Fire chronologies for Smith-Dorrien, Upper Kananaskis, Pocaterra and Lower Kananaskis Valleys.

Smith-Dorrien		Upper Kananaskis		Pocaterra		Lower Kananaskis	
Fire Years	Interval between Fires	Fire Years	Interval between Fires	Fire Years	Interval between Fires	Fire Years	Interval between Fires
1973	69	1967	77	1920	62	1933	13
1904	64	1890	32	1858	26	1920	30
1840	75	1858	20	1832	29	1890	4
1765	33	1838	95	1803	75	1886	6
1732	20	1743	15	1728	16	1880	22
1712		1728		1712		1858	18
						1840	37
						1803	29
						1774	9
						1765	22
						1743	11
						1732	4
						1728	16
						1712	

location. The area east of Lower Kananaskis Lake (Facility Zone) is covered by extensive tracts of even-aged lodgepole pine regeneration as a result of the fires in 1920, 1890 and 1858. Remnant stands on the edge or within these fires have the most complex fire history in terms of age structure and scar information.

The absence of lodgepole pine in some areas of Kananaskis Provincial Park does not necessarily indicate the absence of fire. On north-facing slopes in the Smith-Dorrien Valley only Engelmann spruce and subalpine fir have regenerated after the 1904 fire. Fire scars found on alpine larch suggest that it may be an important pioneer tree species at high elevations (e.g. Highwood Pass area). Stands at high elevation in Kananaskis Provincial Park may have been disturbed by fire sometime in the past even though direct fire history information was not present (i.e. fire scars, lodgepole pine regeneration or charcoal in the soil), as indicated by the 1967 and 1973 fires which burned to timberline. These stands may also have been disturbed by snow avalanches, talus slope movement and landslides. These factors made determination of the fire regime at high elevation a difficult task.

C. Fire Year Maps

Maps are presented for 20 fire years from 1712 to 1973 (Figures 8 to 18). These fire-year maps provide the best estimate of the areal extent of fires determined from

STAND ORIGIN

Legend

1	1920	Rs
2	1890	Rs
3	1920	SL
	1890	Rs
4	1920	SL
	1890	Rs
	1858	Rs
4.5	1920	SL
	1890	RsL
	1886	SL
	1858	Rs
5	1920	SL
	1858	Rs
6	1858	Rs
7	1890	RsL
	1858	Rs
8	1920	SL
	1858	SL
	1774	RsN
	1743	Rs
	1712	RsN
9	1432	RsW
10	1616	RsW
11	1920	RsL
	1890	Rs
	1858	RsL
	1765	SN
	1732	Rs
	1691	R
12	1765	Rs
	1712	Rs
13	1920	RsL
	1890	Rs
	1840	RsL
	1803	SN
	1732	Rs
	1712	Rs
	1691	R
14	1712	Rs
15	1732	Rs
16	1904	Rs
17	1765	Rs
18	1920	SL
	1890	SL
	1732	Rs
	1712	Rs
	1691	R
19	1920	SL
	1890	Rs
	1765	RsL
	1712	RsL
	1661	RDF
	1594	RDF
20	1920	SL
	1880	SL
	1803	Rs
	1765	Rs
	1691	R
21	1630	RsW
22	1858	SL
	1803	Rs
	1712	Rs
23	1920	RsL
	1858	RsL
	1803	Rs
24	1712	Rs
25	1832	RsL
	1712	RAL
	1661	RAL
	1614	RAL
26	1650	RsW
27	1803	Rs
	1765	Rs
	1732	Rs
	1691	R
28	1656	RsW
29	1904	SL
	1551	RsW
29.5	1551	RsW
30	1904	SL
	1732	Rs
	1712	RsW
31	1890	Rs
	1765	SNR
	1732	SNR
	1712	SN
32	1732	RsN
	1712	RsW
	1691	SNR
33	1904	SL
	1858	R
34	1712	RsW
35	1691	RsW
36	1691	R
	1645	R
37	1840	Rs
	1803	Rs
	1685	R
38	1712	RsL
	1685	R
	1658	R
39	1646	RsW
40	1852	RsL
	1712	Rs
41	1973	AFS
42	1967	RsL
43	1586	R
43.5	1586	RsW
44	1858	RsL
	1728	RsL
	1712	RsL
	1674	R
45	1839	RsW
46	1674	RsW
47	1803	RAL
	1642	RAL
	1557	RAL
48	1705	RAL
49	1838	SL
	1858	Rs
	1728	RsL
	1712	Rs
	1674	R
50	1933	AFS
W	WATER	

Key to Letters

R	Regeneration for Lodgepole pine - no scar information near to cross-date to fire year
Rs	Regeneration for Lodgepole pine - scar information near to cross-date to fire year
RsL	Regeneration for Lodgepole pine - scar to date fire year on a living tree in that stand
RsN	Regeneration for Lodgepole pine - scar to date fire year on snag in that stand
RsW	Regeneration for Engelmann spruce - to date stand origin
RDF	Regeneration for Douglas-fir - to date stand origin
RAL	Regeneration for Alpine Larch - to date stand origin
SL	Scar to date fire year on living tree - no regeneration
SN	Scar to date fire year on snag - no regeneration
SNR	Regeneration for Lodgepole pine from snag
AFS	Alberta Forest Service fire records

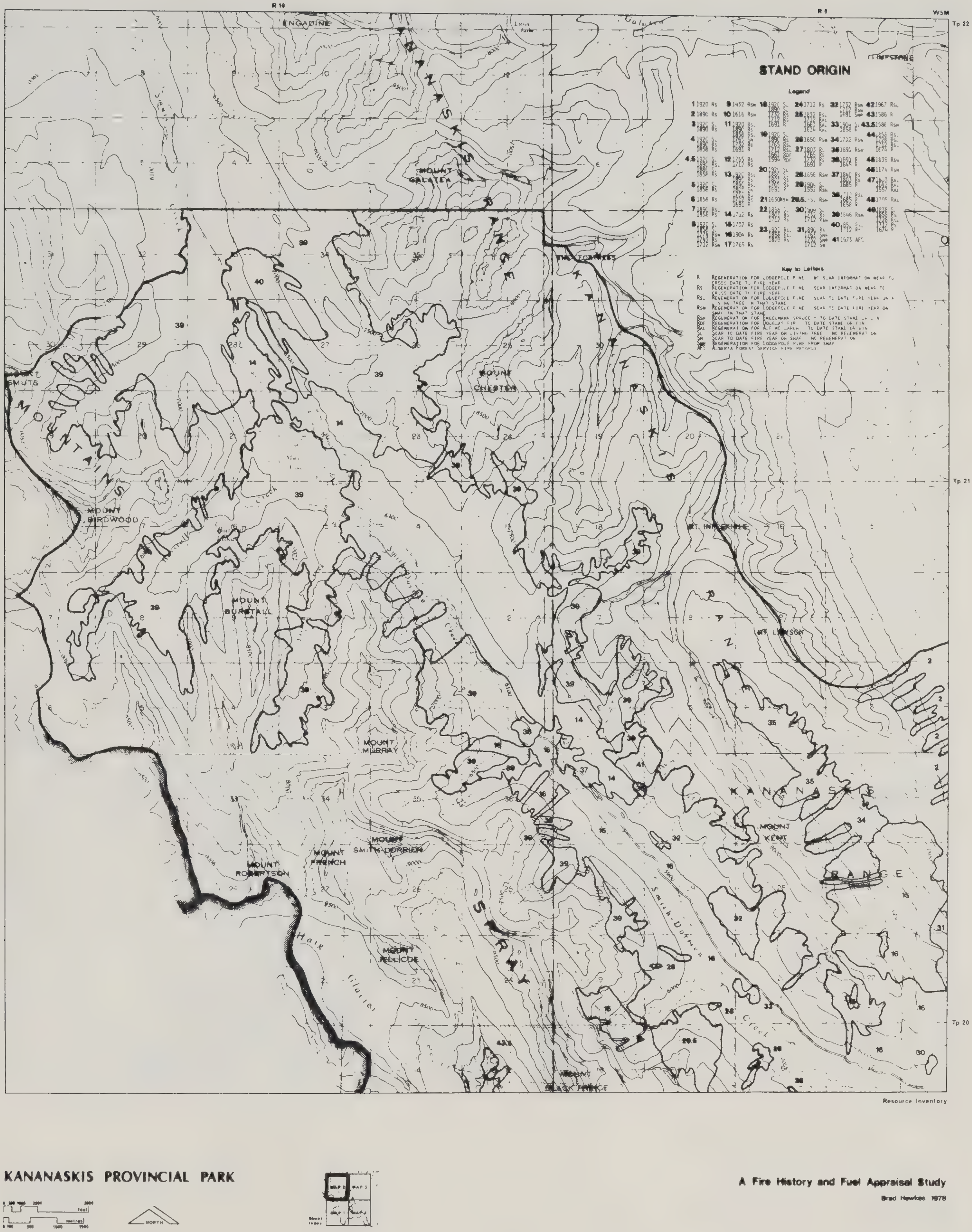

Figure 4. Stand origin map. Part I

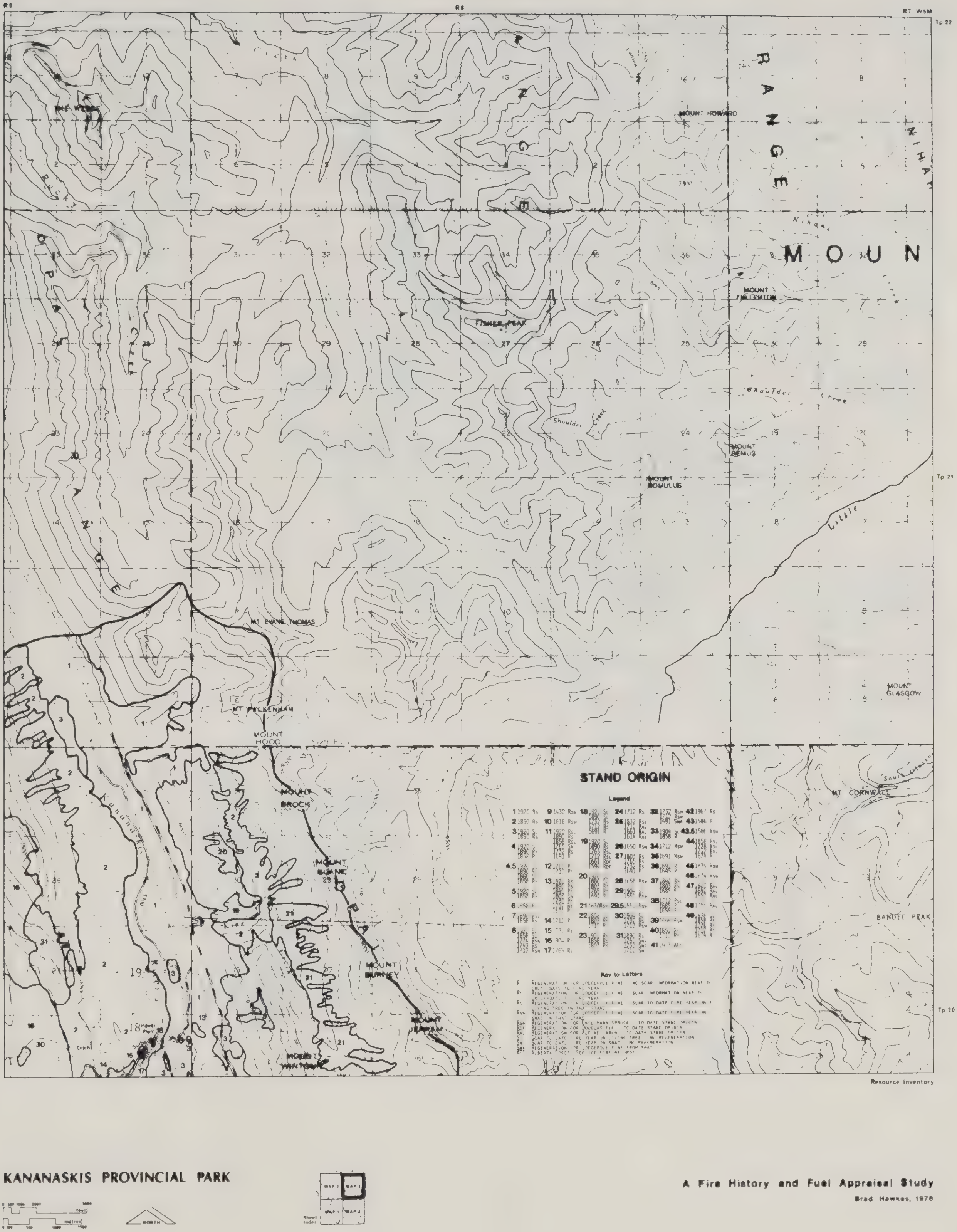

Figure 5. Stand origin map. Part II

Figure 6. Stand origin map. Part III

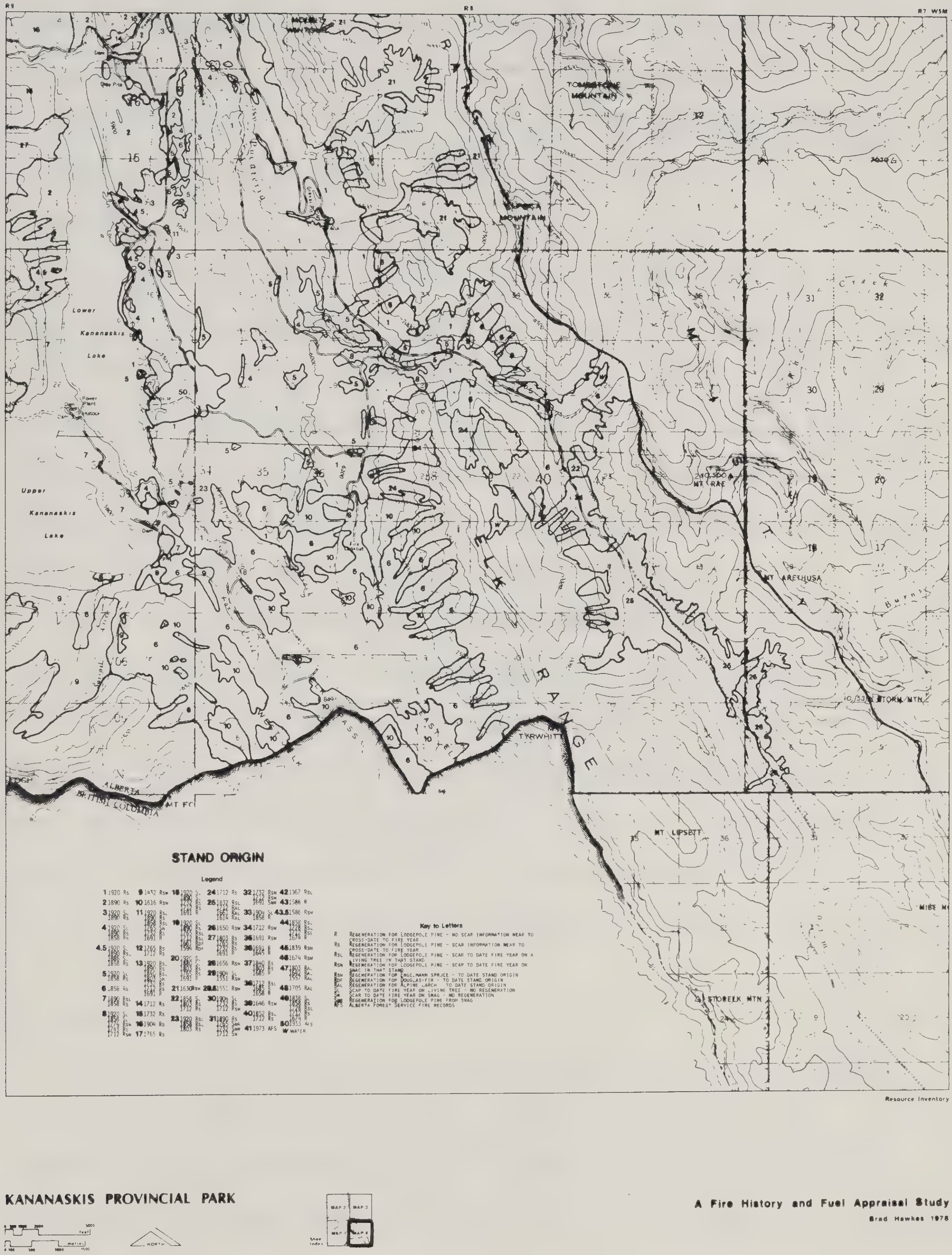

Figure 7. Stand origin map. Part IV

Alberta Forest Service fire records and fire history information. The areal extent of fires before 1832 is tentative because of limited fire history information. The areas of fires illustrated on the fire-year maps are presented in Table 1.

No major fires have occurred since 1920. The two largest fires occurred in 1858 (9017 ha within the Park) and 1712 (9132 ha within the Park), each covering over 17% of the Park's total area and over 37% of the forested area. Fires in 1920, 1890, 1858, 1803 and 1712 burned areas outside the Park boundaries, so that areas presented in Table 1 are less than the total area burned.

Not all areas within the shaded sections of the fire year maps were entirely consumed by the fire. The stand origin map illustrates many remnant stands that survived within and on the edge of fires in Kananaskis Provincial Park (Figures 4 to 7 and Appendix 5). Many of these stands were thinned and scarred by fire moving through the understory and perhaps torching occasional crowns.

D. Burn Direction

Fire scars indicate localized direction of the flaming front (Tande 1977) but do not necessarily indicate the overall spread direction. This is because localized winds caused by difference in topography or the fire may be different from the general winds. Prevailing wind patterns during July and August were analyzed for the period 1966 to

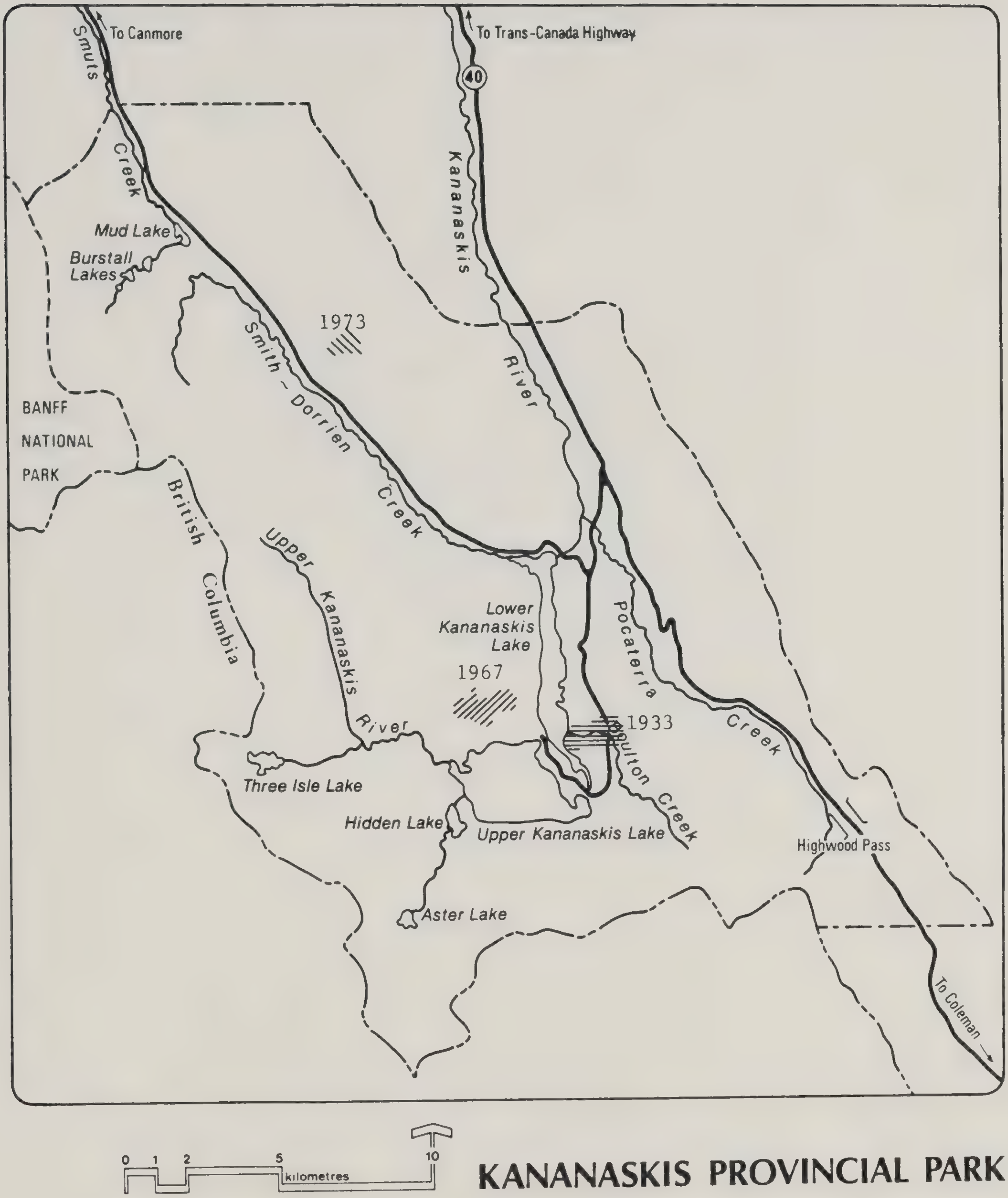

Figure 8. Areal extent of the fires between 1921 and 1978 in Kananaskis Provincial Park.

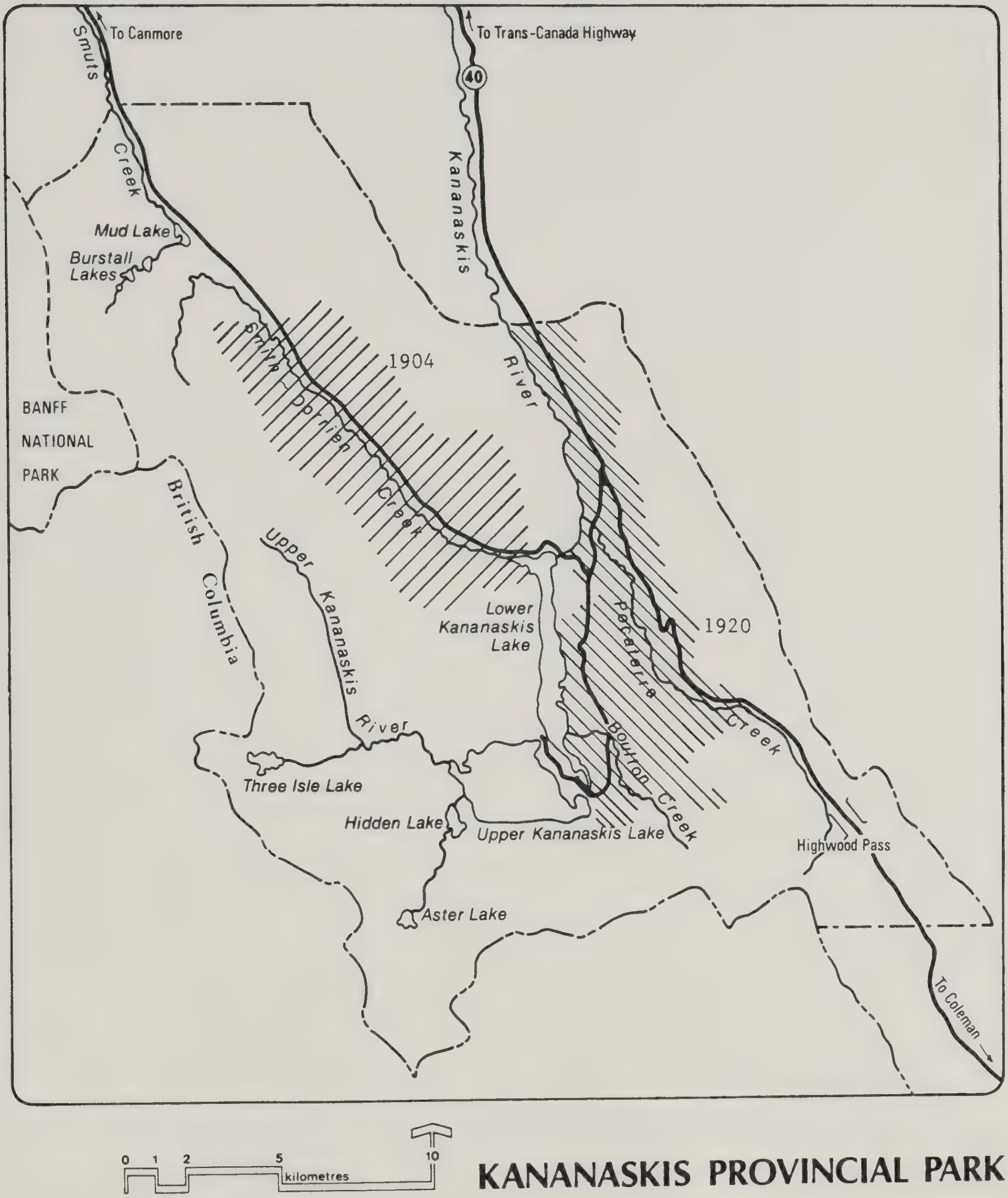

Figure 9. Areal extent of the fires between 1891 and 1920 in Kananaskis Provincial Park.

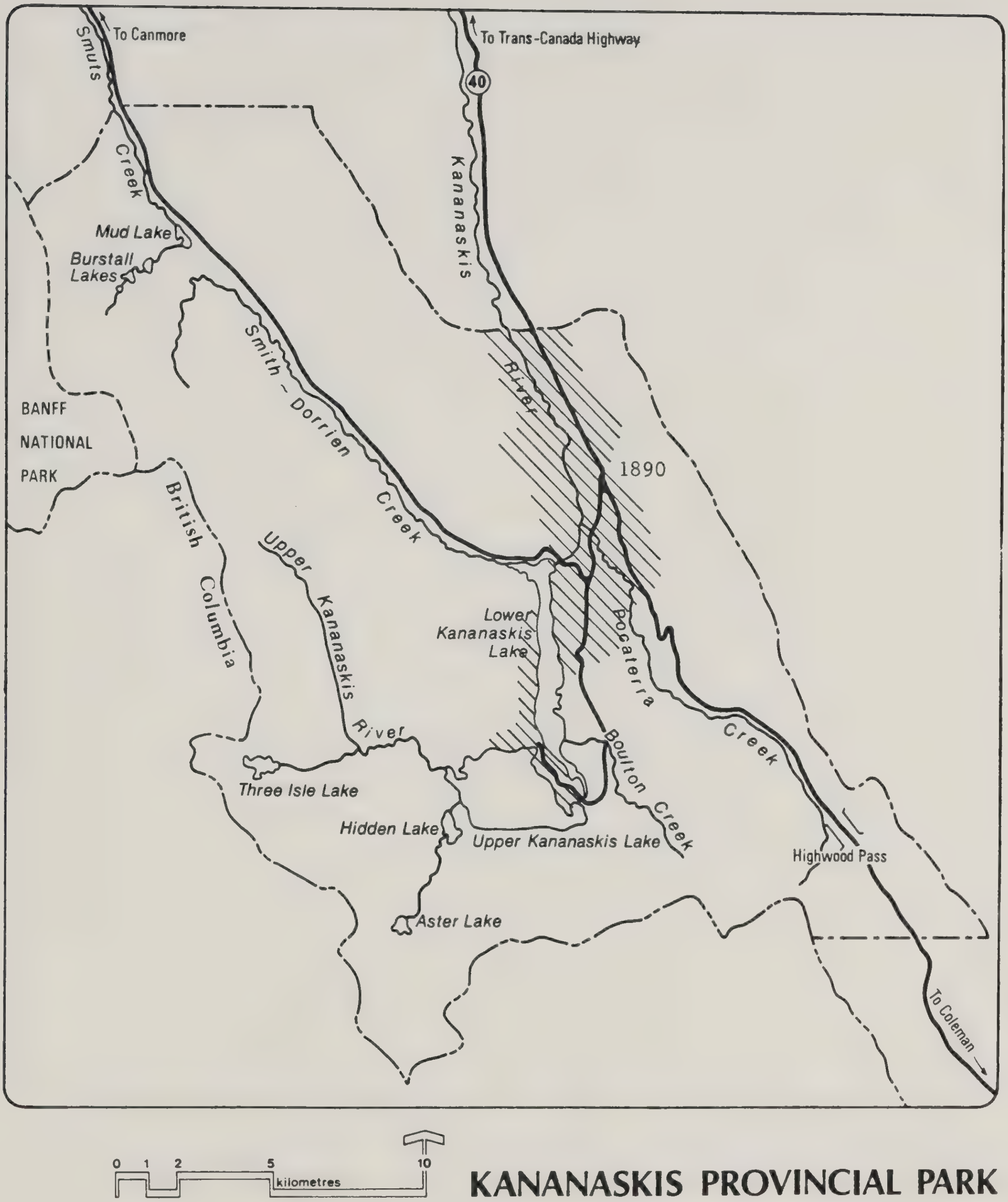

Figure 10. Areal extent of the 1890 fire in Kananaskis Provincial Park.

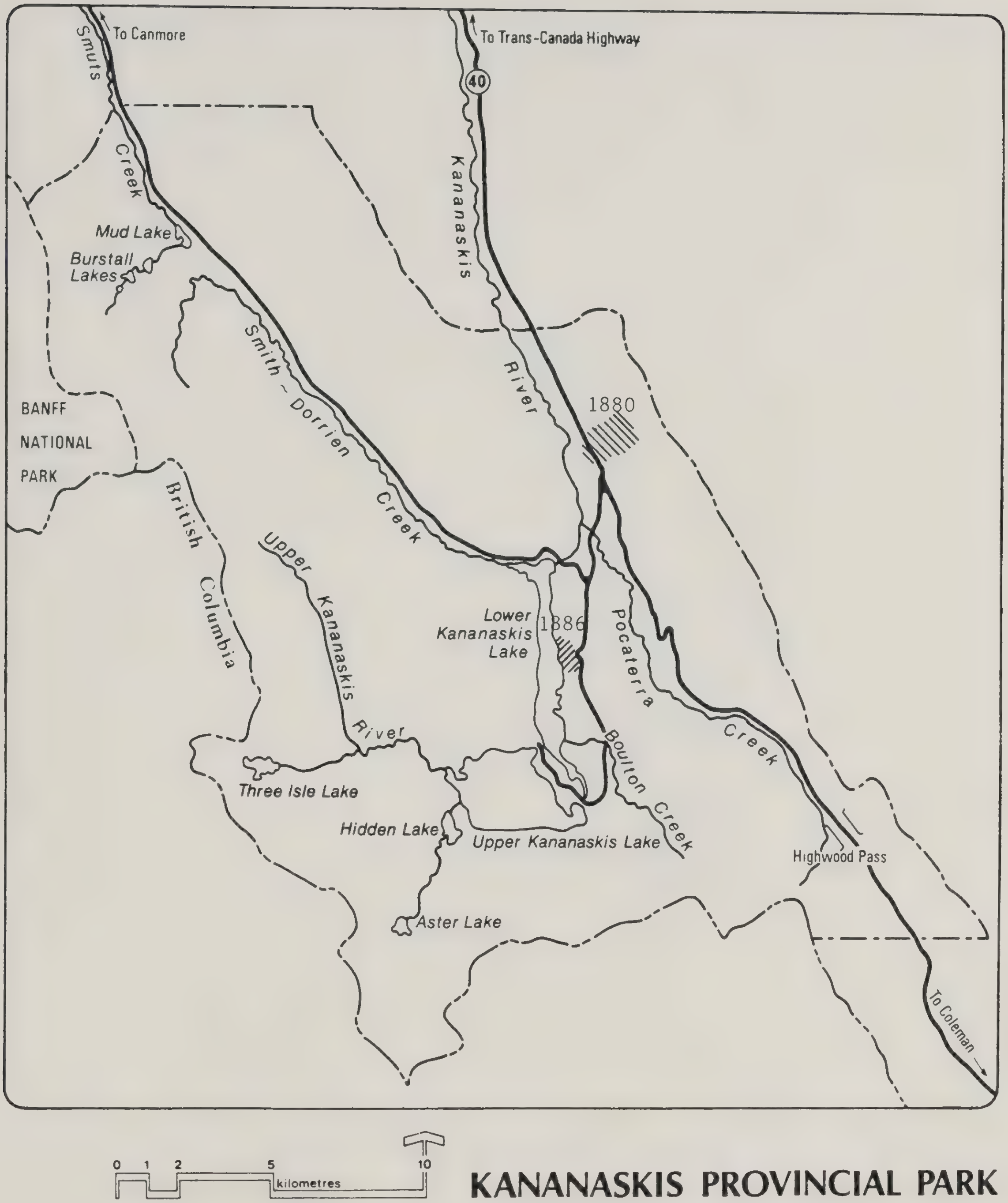

Figure 11. Areal extent of the fires between 1880 and 1889 in Kananaskis Provincial Park.

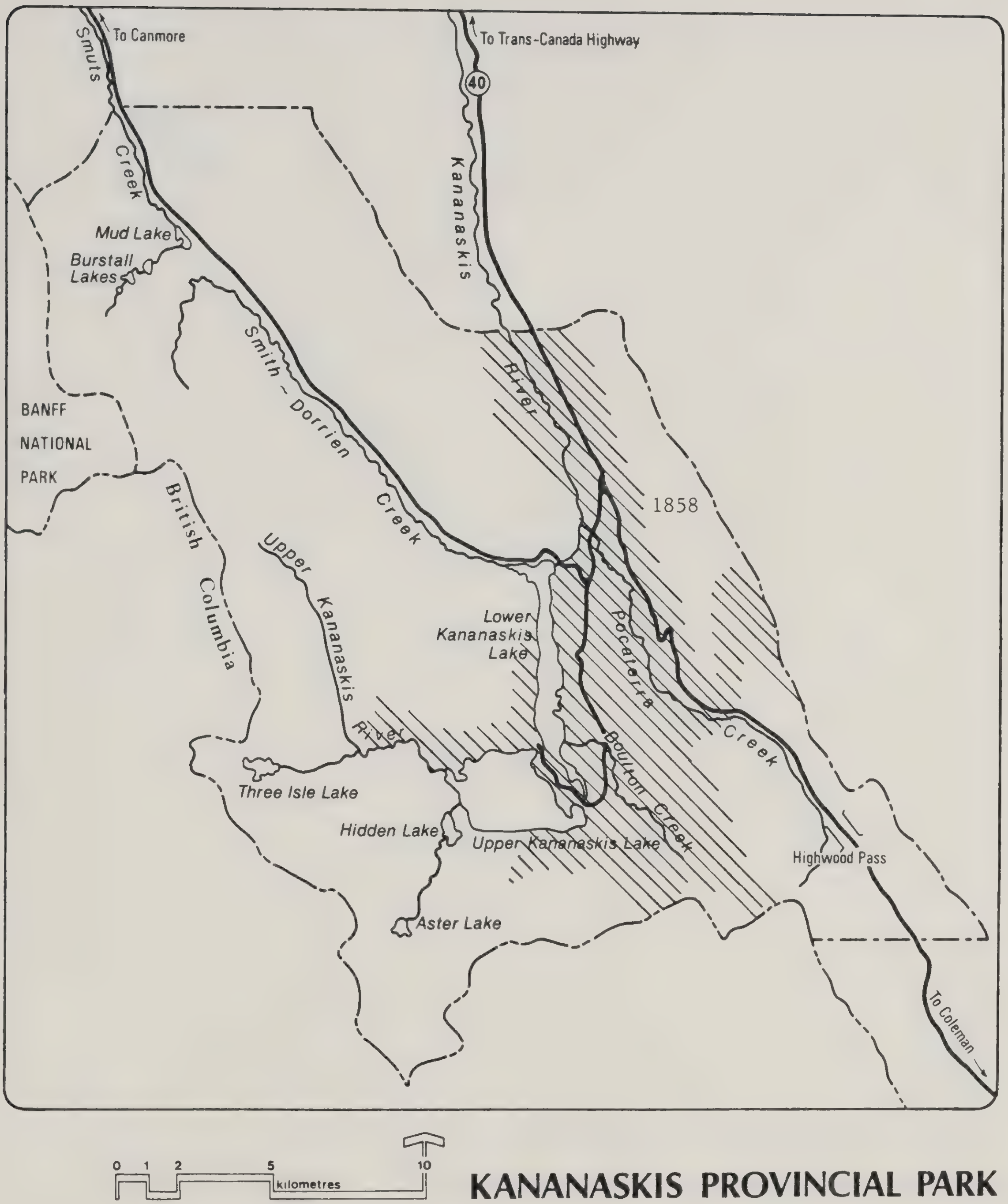

Figure 12. Areal extent of the 1858 fire in Kananaskis Provincial Park.

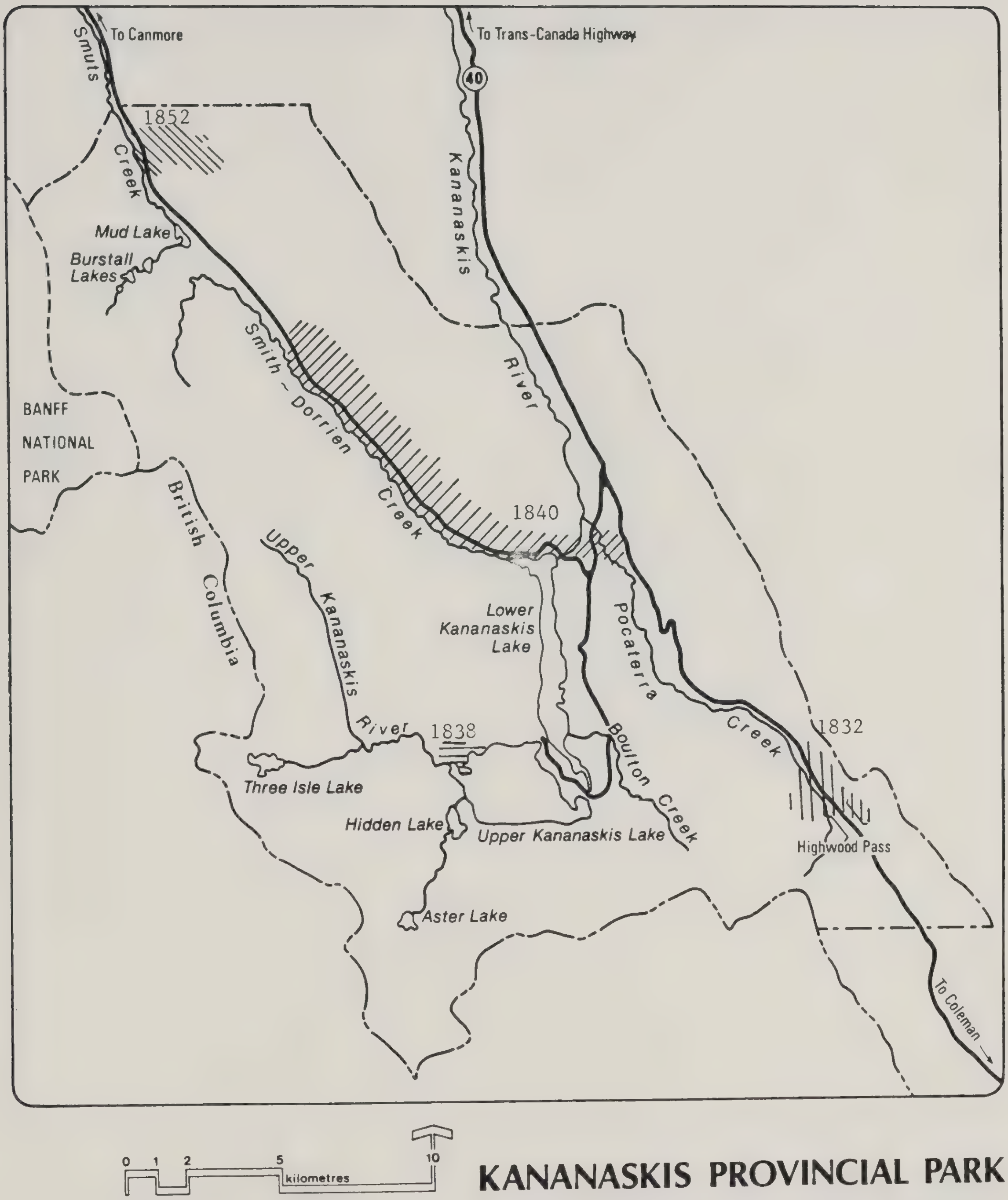

Figure 13. Areal extent of the fires between 1832 and 1857 in Kananaskis Provincial Park.

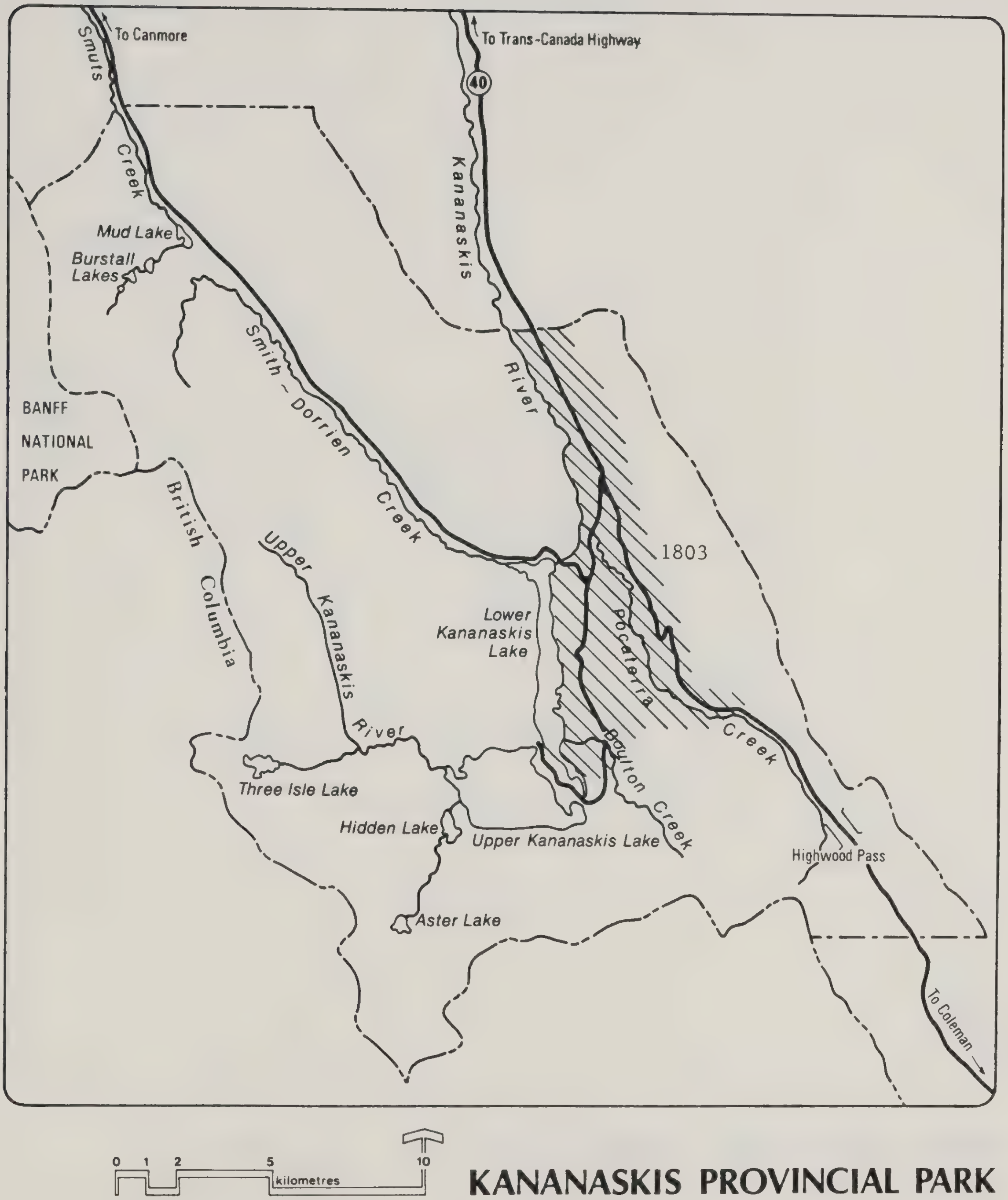

Figure 14. Areal extent of the 1803 fire in Kananaskis Provincial Park.

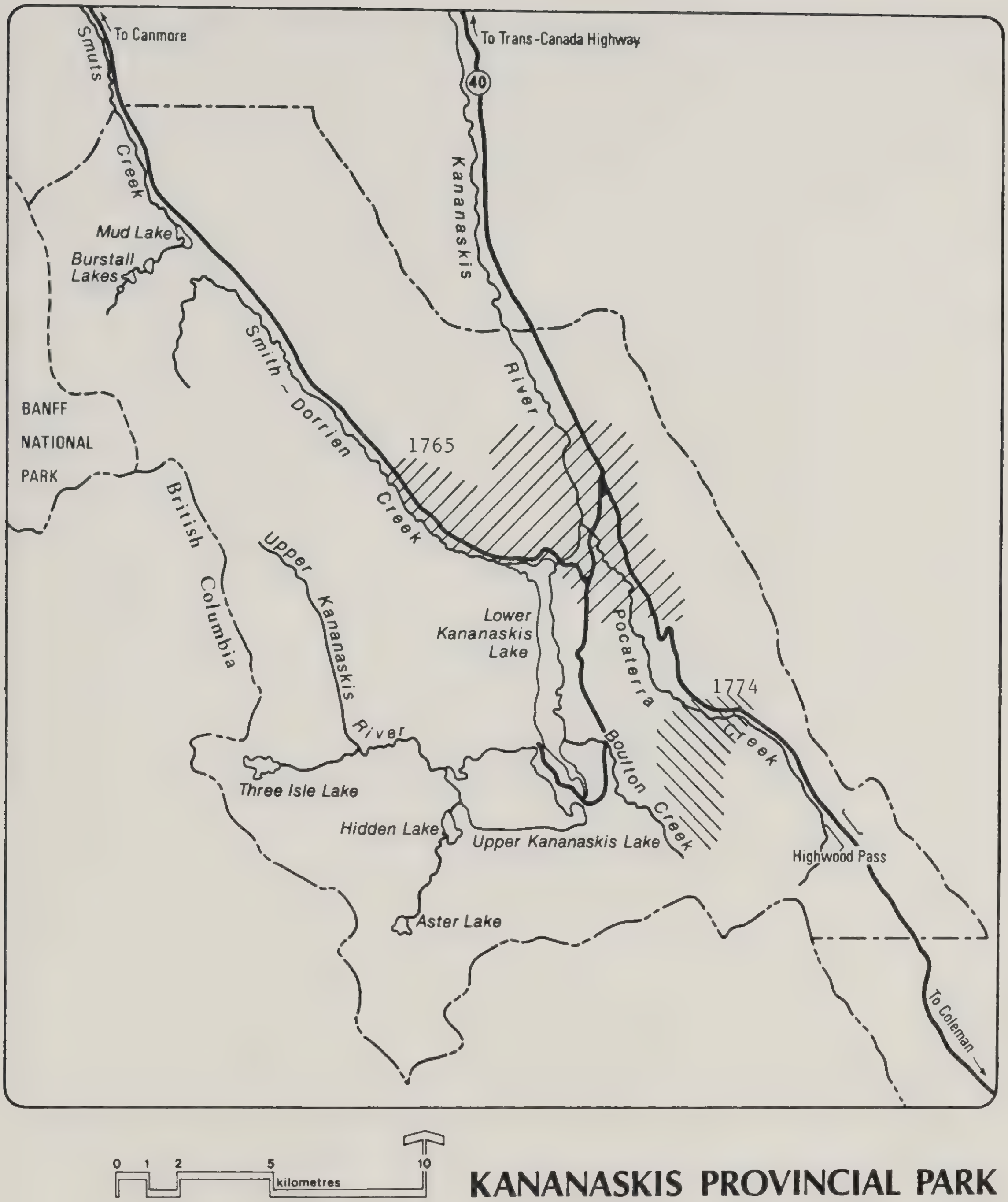

Figure 15. Areal extent of the fires between 1765 and 1802 in Kananaskis Provincial Park.

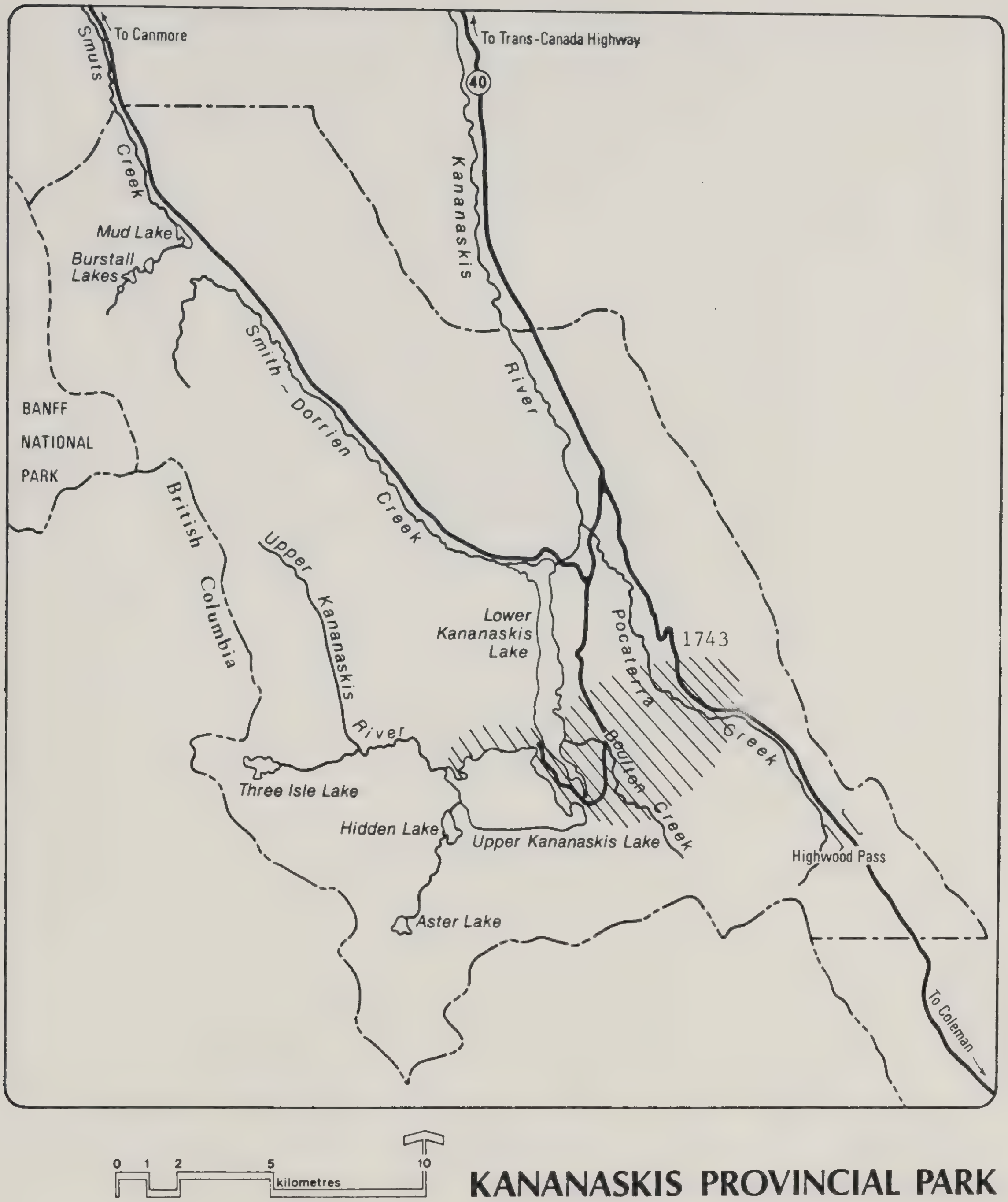

Figure 16. Areal extent of the 1743 fire in Kananaskis Provincial Park.

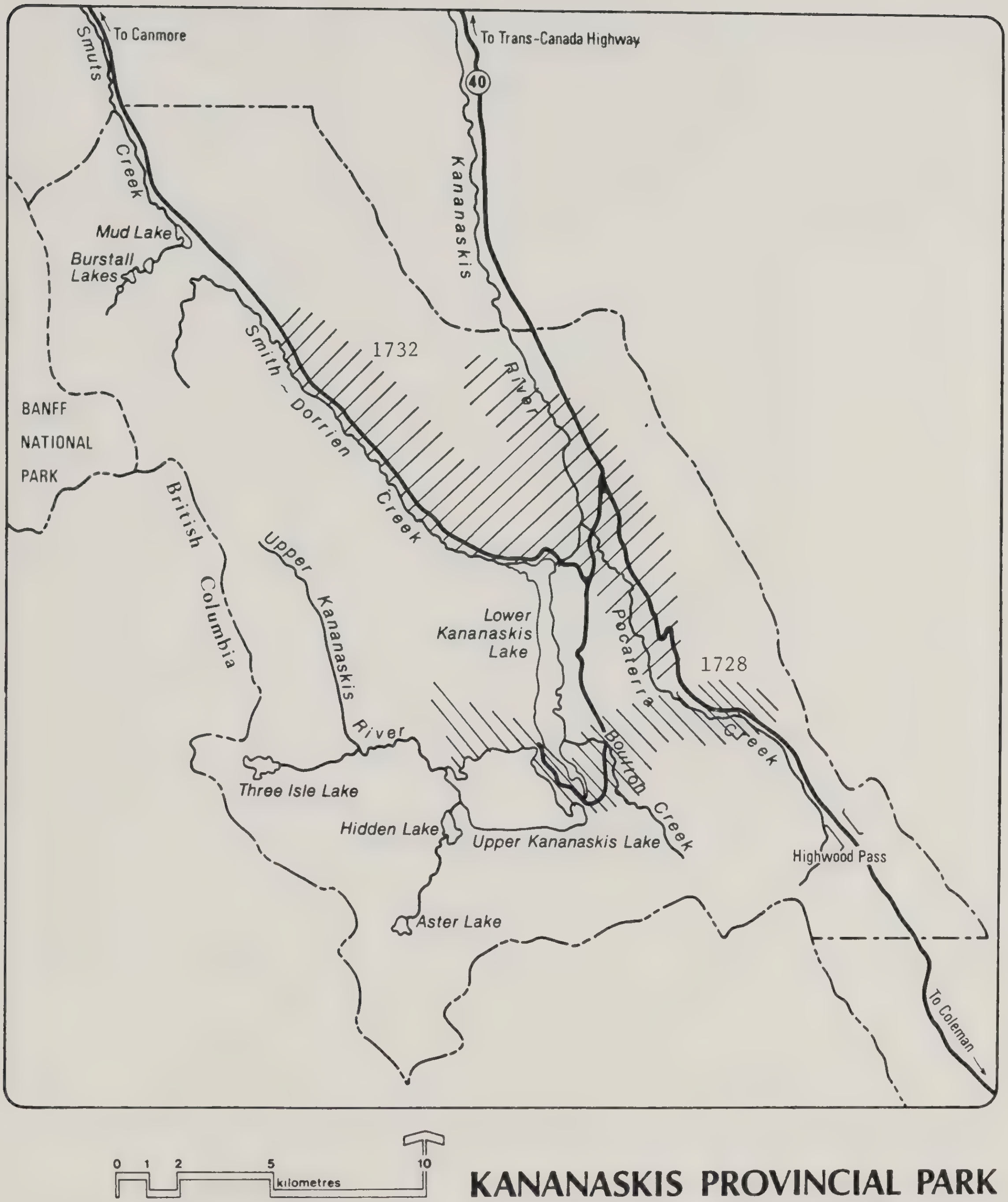

Figure 17. Areal extent of the fires between 1728 and 1742 in Kananaskis Provincial Park.

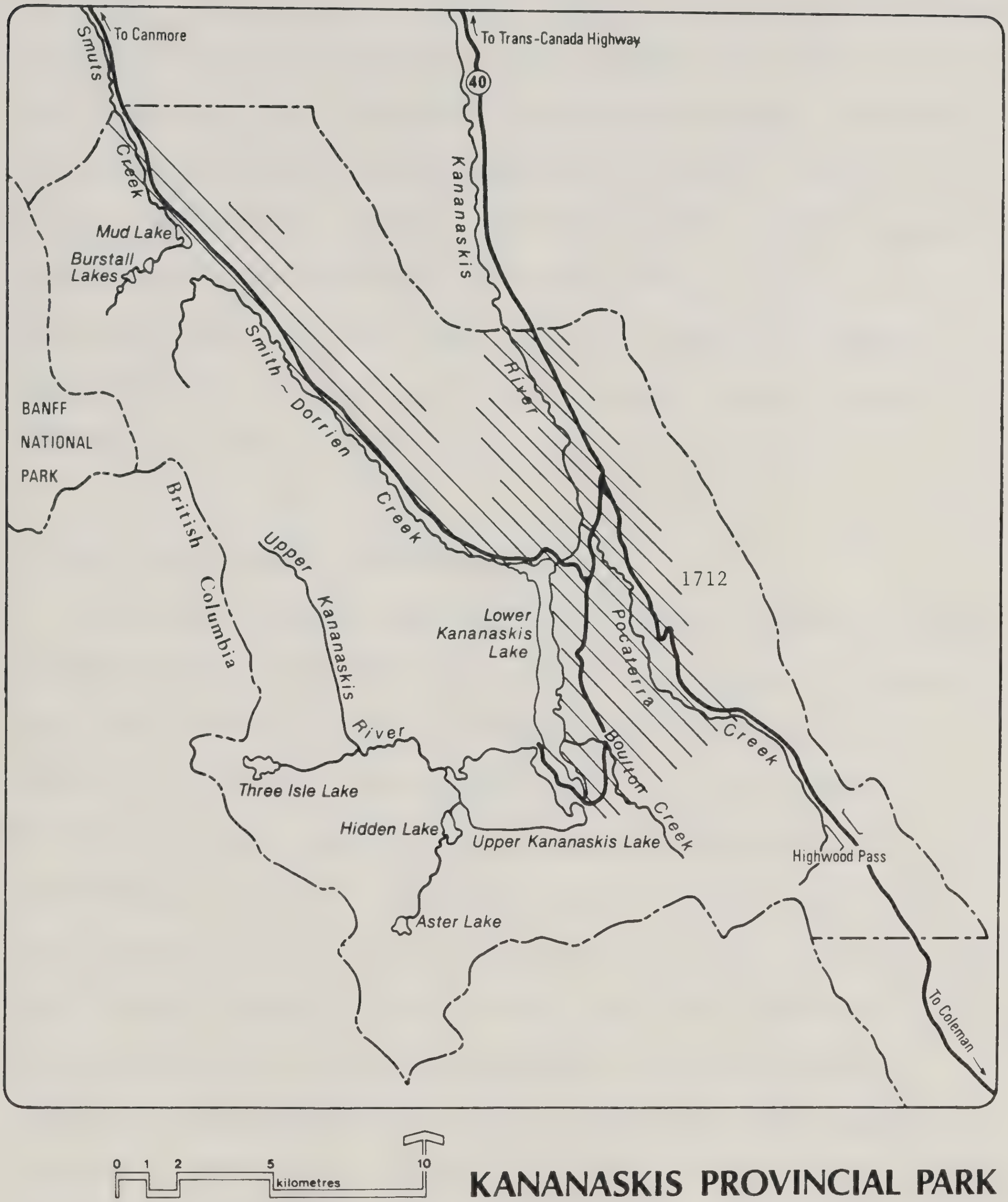

Figure 18. Areal extent of the 1712 fire in Kananaskis Provincial Park.

1971 for Kananaskis Fire Lookout (Figure 19). The analysis indicated that 83% of July and August winds come from the west and south and are funneled down the Kananaskis Valley. Documentation on the Galatea Fire (1936) just north of the Park indicated that "blowup" conditions occurred because of a strong dry wind from the southwest (Alberta Forest Service 1936a). The Quarrie or Elk Pass Fire (1936) in Elk Valley came within one half mile of the Elk Pass, but rain and a fire crew held it. This fire was also spread by southerly winds blowing up the Elk Valley (Alberta Forest Service 1936b and British Columbia Forest Service 1936).

E. Mean Fire Return Interval

Mean fire return interval (the average number of years between fires) has been expressed in literature in two main ways. The first is based on the average number of years between fires for a given study area (e.g. Kananaskis Provincial Park, Jasper National Park or a particular watershed). The second is based on the average number of years between fires for a given point or stand (usually less than 100 ha) within a study area. The first expression of mean fire return interval (M.F.R.I.) is area-dependent, because it will shorten if the size of the study area is increased. The "point" expression of M.F.R.I. is more useful for comparing results from one study area to another.

The M.F.R.I. (area-dependent expression) for major (>1000 hectares) fires in Kananaskis Provincial Park since

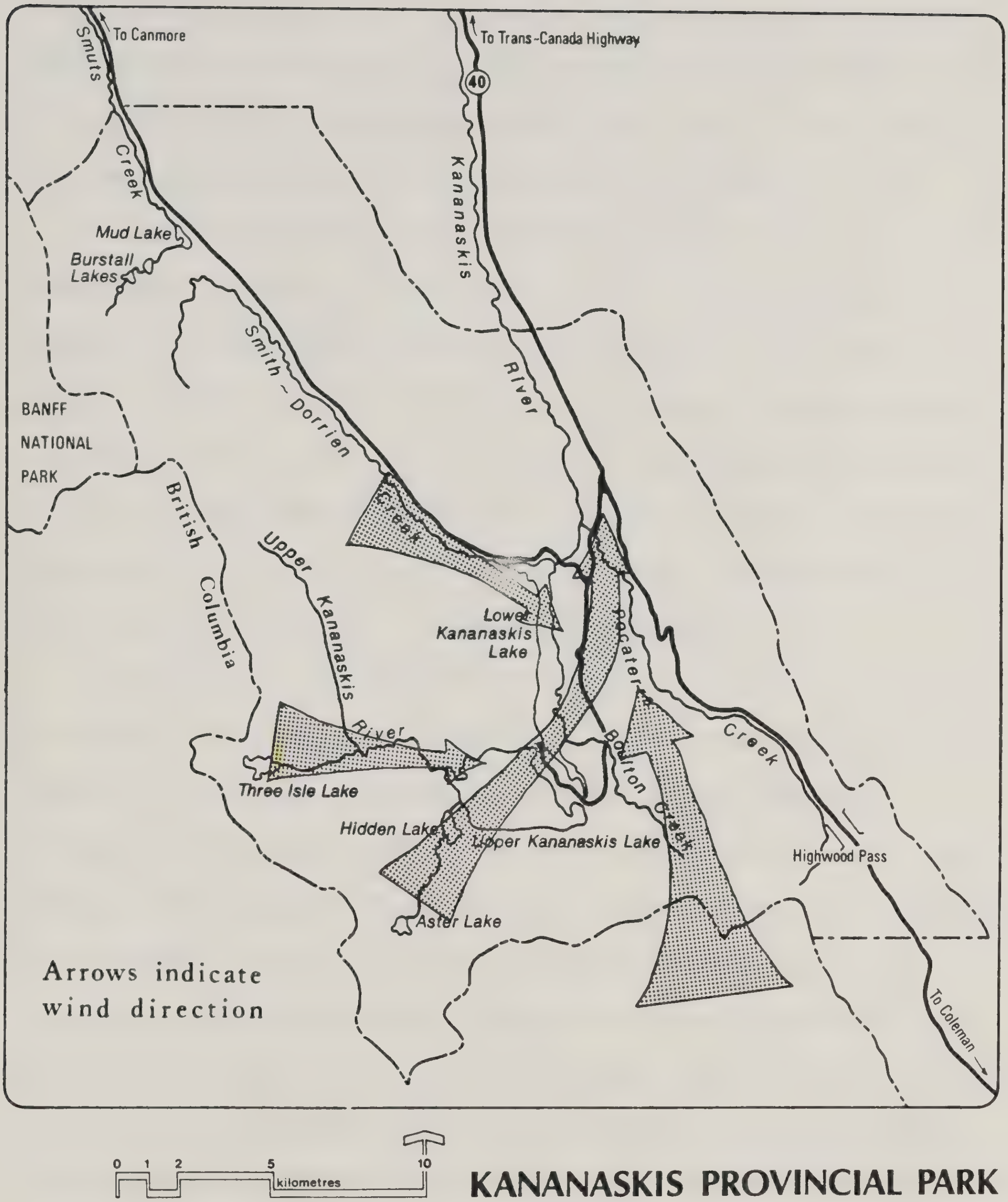

Figure 19. Prevailing wind patterns for July and August in Kananaskis Provincial Park (from Kananaskis Lookout records, 1966-71)

1712 was 21 years with a range of 11 to 38 years. The M.F.R.I. for all fires in Kananaskis Provincial Park was 14 years with a range of 2-38 years. This latter estimate is conservative because many low-intensity surface fires might not be detected. This was because scarring did not occur or fire evidence has been destroyed by more recent fires.

M.F.R.I. was calculated for four areas within Kananaskis Provincial Park. The Smith-Dorrien Valley had a M.F.R.I. of 52 years. The Upper Kananaskis Valley had a M.F.R.I. of 48 years. The Pocaterra Valley had a M.F.R.I. of 42 years. The M.F.R.I. for the Lower Kananaskis Valley was 17 years. The size of these areas are similar but the Lower Kananaskis Valley has a lower elevational range than the other three which are at similar elevations.

M.F.R.I. was calculated on a point basis to determine the effect of elevation, aspect and ecological subzone[1] on M.F.R.I. A two-way analysis of variance was done for elevation and aspect (ANOVA Table in Appendix 3). All fire history plots were separated into eight cells. Twelve plots were randomly picked for each cell for the analysis of variance. The elevational differences were significant at the 95% probability level. The M.F.R.I. for the north aspect was significantly different at the 95% probability level from the south, west and east aspects (Scheffe multiple comparison results in Appendix 3). Fire history plots wer stratified according to their location (lower (n=88) or

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[1] as defined by Walker *et al.* (1978)

upper subalpine (n=13) subzones). A "t" test of the means indicated that the two ecological subzones had significantly different M.F.R.I. at the 95% probability level ("t" test results in Appendix 3). The results for elevation, aspect and ecological subzone were:

Elevation	M.F.R.I. (years)
1525-1830m	90
1830-treeline (Approx. 2300m)	153

Aspect	M.F.R.I. (years)
North	187
South	104
West	101
East	93

Ecological Subzone	M.F.R.I. (years)
Lower Subalpine	101
Upper Subalpine	304

F. Fire Occurrence and Climate

No precipitation records could be found before 1966 for Kananaskis Provincial Park. Climatic data were available for Banff National Park for the period 1895-1978, although the climate appeared to be quite different from Kananaskis Provincial Park which was wetter and colder during the summer (Powell and MacIver 1977). Many of the major fires in Kananaskis Provincial Park occurred before 1895.

Ring-width analysis of tree cores, through the techniques of dendroclimatology, yields one source of past climatic information. Changes in precipitation and

temperature have an effect on photosynthesis, respiration and growth, which in turn affect the final width of the ring. In theory, narrow rings could indicate years in which precipitation was below normal, and when fire danger may be presumed to be higher. Some of the problems encountered in relating this information to fires in Kananaskis Provincial Park were:

1. Schultz *et al*. (1970) found that a combination of previous year's precipitation and current year's rainfall was correlated to ring-width variation. In Kananaskis, a period of only two weeks without rain is probably sufficient to allow large fires to develop with the appropriate wind conditions. This may occur during normal precipitation years.
2. Parker (1976) found that temperature rather than precipitation had a better correlation with ring width in Northern Canada. A similar situation probably occurs at high elevation in the Rocky Mountains.
3. Whether or not a fire will occur during a drought period will depend on an ignition source, and the spread of a subsequent fire will depend on wind conditions. High winds (50 km/h) are experienced in Kananaskis Provincial Park almost every summer; these might promote a large fire to develop even during a relatively normal climatic year.

A Douglas-fir ring-width chronology (1600-1967) for Banff National Park, Alberta, is presented in Figure 20 (Parker 1978). All fires in Kananaskis Provincial Park are also illustrated on this figure. Only 30% of major fires (>1000 ha) in the Park occurred during years of below-mean expected growth. The Banff ring-width chronology appears to be a poor indicator of past climatic events (critical July and August precipitation and temperature), which can be correlated to the occurrence of fires in Kananaskis Provincial Park.

A recent development in dendroclimatology is the use of latewood density chronologies. Parker and Henoch (1971) examined the use of Engelmann spruce latewood density for dendrochronological purposes and found that maximum latewood density was highly correlated to August mean maximum temperature values. A maximum latewood density chronology (1750-1967) for Engelmann spruce at Peyto Lake, Alberta (2000 m elevation) (Digital Filter Index Program) is presented in Figure 21 (Parker and Henoch 1971). The filter program produces index chronologies that accentuate year to year variation and "filter out" fluctuations greater than 10 years (Parker 1970). Fires for this period were illustrated on the maximum latewood density chronology. Figure 21 illustrates that 86% of major fires (>1000 ha) occurred during years of above mean maximum latewood density. Seventy-three percent (73%) of all fires in this period occurred during years of above mean maximum latewood

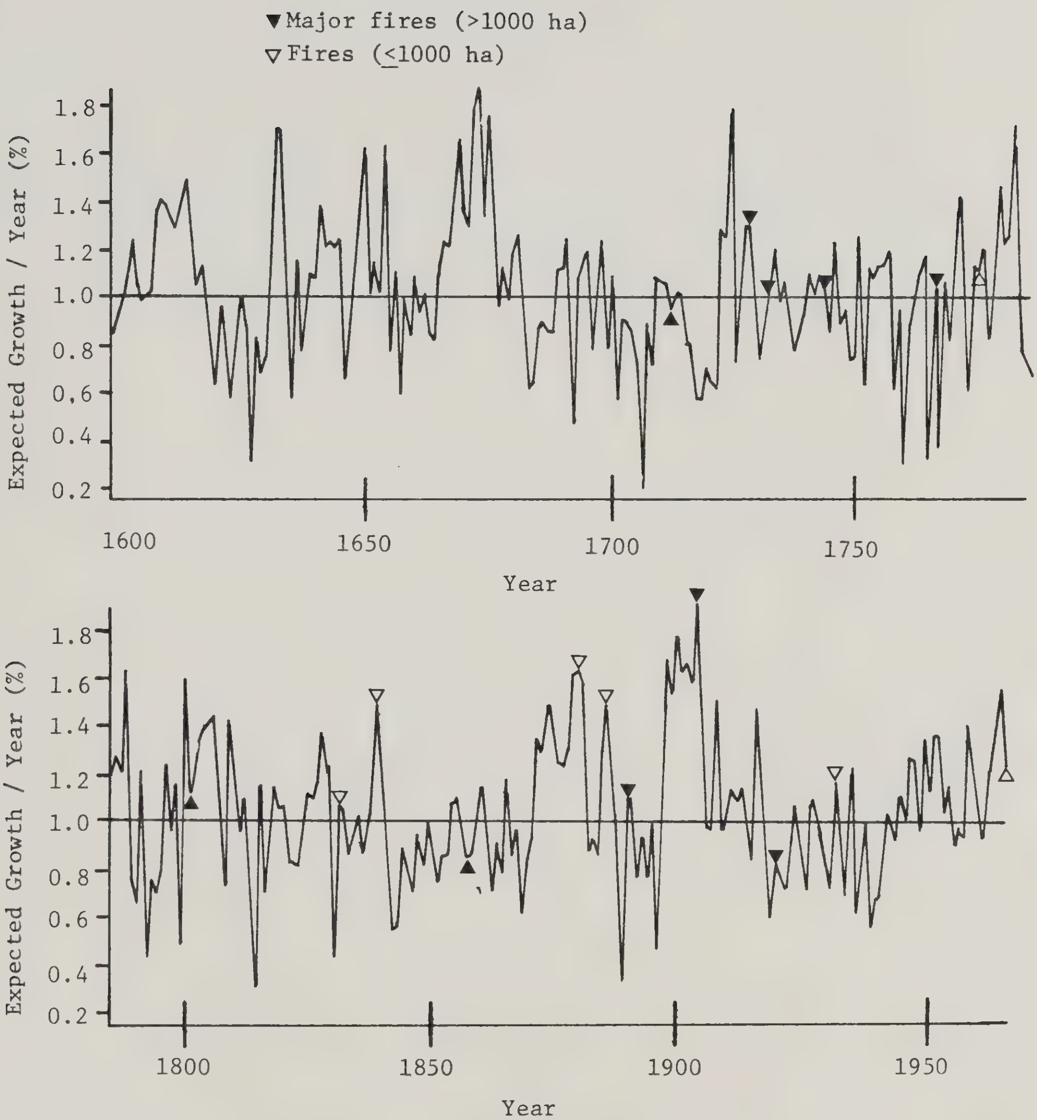

Figure 20. Banff Douglas-fir ring-width chronology (1600-1967) (Parker 1978).

density. This indicates a possible correlation between mean maximum August temperature and fire occurrence in Kananaskis Provincial Park.

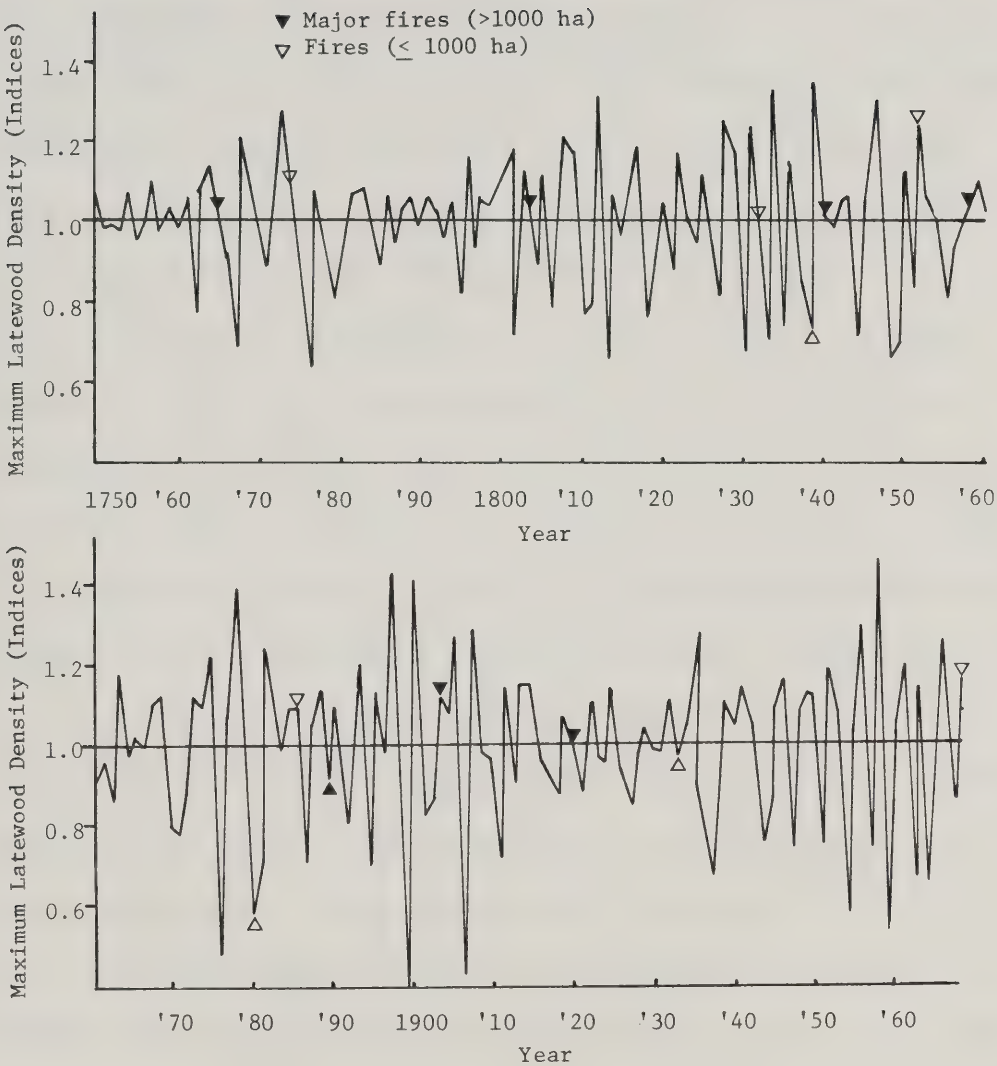

Figure 21. Peyto lake Engelmann spruce maximum latewood density chronology (1750-1967) (Parker and Henoch 1971).

VII. DISCUSSION - FIRE HISTORY

A. Fire Chronology

A comparison of major fire years in Kananaskis Provincial Park and fire years determined in studies in Jasper, Alberta, northern U.S. Rocky Mountains and Minnesota showed some common fire years (Table 3). Common major fire years in Kananaskis Provincial Park and in Jasper National Park (Tande 1977) were 1904, 1858, 1727±2[1] and 1714±2[1]. Mos major fire years determined by Tande (1977) in Jasper National Park had no corresponding fire in Kananaskis Provincial Park. Fires may not have occurred during these major fire years because of a lack of an ignition source (dry lightning strike or man) or conducive fire weather conditions in Kananaskis Provincial Park. Common fire years in Kananaskis Provincial Park and areas in the Western States and Minnesota suggest that subcontinental weather patterns may create favourable weather conditions for fires over a wide area. This comparison was much too limited in detail to draw more definite conclusions on any relationship between major atmospheric circulation patterns and fire occurrence.

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[1] tentative fire dates from two Douglas-fir sections in Jasper, Alberta, which were found to vary by ±2 yrs. when compared to known fire dates of the area in which they were collected (Tande 1977).

Table 3. Comparison of major fire years (>1000 ha) in Kananaskis Provincial Park with other fire years found in Alberta, Western United States and Minnesota.

Kananaskis Provincial Park	Wyoming (Houston 1973)	Montana** (Sneck 1977)	Montana** (Arno 1976)	Jasper Nat. Park (Tande 1977)	Minnesota (Frissell 1973)	Minnesota (Heinselman 1973)**
1920*						1920
1904*			1904	1904*		1904
1890*		1890				1890
1858*			1858	1858*		
1840*			1840			
1803*	1803*	1803	1803		1803*	
1774*		1774	1774			
1765*		1765				
1743*			1743			
1732*						
1728*	1728			1727±2*		
1712*			1712	1714±2*	1712*	1712

* Major fires

** Major fires not distinguished for study areas

B. Age Class Distribution

The distribution of age classes of forest stands in Kananaskis Provincial Park was not similar to the age-class distribution of a large area in Minnesota (Table 4). The age class distribution in Kananaskis had two peaks; one at 40-120 years and the other at 320-400 years. The age class distribution described by Heinselman (1973) had one peak at 40-120 years. Tande (1977) also found one peak in the age class distribution of forests in Jasper National Park at 40-120 years. The difference found in Kananaskis may be due to the presence of more high-elevation forests with a longer M.F.R.I. The small size of the Kananaskis study area compared to other study areas may over-emphasize the older age classes (Van Wagner, pers. comm. 1978). The lack of forest stands in the 0 to 40 age class is a result of no major fires occurring since 1920.

The absence of major fires since 1920 may be due to fire suppression activities by the Alberta Forest Service since the early 1940's. Other fire history studies have shown a decrease in burned area per year since the initiation of fire suppression (Heinselman 1973, Arno 1976, Sneck 1977, and Tande 1977). The time since the last major fire in Kananaskis exceeds the longest fire-free interval between major fires from 1712 to 1920 (i.e. 38 years).

Table 4. Age-class distribution of forest stands in Kananaskis Provincial Park as of 1977 and in Minnesota as of 1973.

Age Class (yrs)	Area (ha)	Percent of Total Forested Area Kananaskis (%)	Percent of Total Forested Area Minnesota (Heinselman 1973) (%)
>0 ≤40	321	1.3	2.4
>40 ≤80	7276	29.3	33.2
>80 ≤120	5300	21.4	48.1
>120 ≤160	505	2.0	4.0
>160 ≤200	551	2.2	5.7
>200 ≤240	45	0.2	3.1
>240 ≤280	2569	10.4	0.9
>280 ≤320	345	1.4	2.4
>320 ≤360	5031	20.3	-
>360 ≤400	2225	9.0	0.2
>400 ≤440	177	0.7	-
>440 ≤480	-	-	-
>480 ≤520	-	-	-
>520 ≤560	446	1.8	-
Total	24791		

C. Relative Severity and Intensity of Past Fires

Fire intensity (KW/m) of past fires cannot be determined from fire history information. Various authors have discussed the relative severity or intensities of past fires from their stand and fire history information (Arno 1976, Sneck 1977 and Tande 1977). These inferences about fire intensities are complicated by complex relationships between fire intensity, fuel characteristics, weather, topography and fire effects. Tande (1977) suggested that high fire intensities in high elevation areas of Jasper National Park had created large areas of even-aged lodgepole pine-dominated forests. Gabriel (1976) found in northwestern Montana that, in the higher elevation sections of the Bob Marshall Wilderness, Montana, large stand-destroying fires had occurred but with a sporadic pattern of stand destruction even during relatively high-intensity fires. The sizes and intensities of fires in Kananaskis Provincial Park seemed to be characteristic of the higher elevation sections of other study areas in the Northern Rocky Mountains. Most fires in the lower elevation sections of Kananaskis Provincial Park (<2000 m) seemed to have been large (>1000 ha), stand-destroying fires of medium to high fire intensities, with low to moderate fire intensities on the edge and backing sections.

Relative severity or intensity in this and other studies was determined by using the type of stand replacement (i.e. even-aged or multiple-aged forest),

density of regeneration and the number of fire-scarred remnants as indicators. Generalized fire effect relationships are postulated by Brown (1973) and Muraro (1971). The applicable generalizations are:

1. High-intensity fires on mesic and wet sites with an abundant seed source can create dense stands (e.g. areas of the 1904 and 1920 fire). On dry sites, fires of high intensity can impoverish the soil and result in poor stocking (e.g. areas of the 1967 and 1973 fires).
2. As weather conditions increase to create blowup conditions, temperatures within the fire may become lethal to seeds, resulting in a poorly stocked stand (e.g. areas of the 1920 and 1973 fires).
3. Low-intensity fires can create an open stand because of poor seedbed conditions and unopened cones. Competition from resprouting herbs and shrubs may also affect regeneration. But under dry duff moisture conditions, an adequate seedbed may be prepared and good stocking may take place (e.g. edges of the 1920 fire).

Above 2000 m in elevation, stand-destroying fires have occurred at longer intervals (>300 years). Lightning-struck trees observed in the Lawson Lake area (>2000 m elevation) suggested that wet conditions due to late snow melt, wet lightning strikes, and/or poor fuel continuity seemed to limit the growth of fires. Areas around Three-Isle, Lawson,

Maude, and Burstall Lakes (all above 2000 m elevation) had no direct evidence (fire scars, even-aged stands or charcoal in the soil) of large stand-destroying fires, but had sporadic lightning-struck trees. The role of fire in the upper subalpine subzone needs more intensive investigation before more definite conclusions can be drawn.

The Galatea Fire (1936) which burned just north of Kananaskis Provincial Park was the only large (>1000 ha) fire since 1920 which had documentation to assess possible expected fire behavior during major fires in Kananaskis Provincial Park. P. Campbell, a ranger for Alberta Forest Service, described the fire on August 9th, six days after it started:

> "About 12 noon on the 9th, several spot fires were noticed on the north side of Galatea Creek near the mouth.... but wind developed into a gale... by 1 p.m., fire was raging inferno in the old burn on the north side of Kananaskis River north from the mouth of Galatea Creek. It climbed up the side of Mt. Bogart and where it reached the top, live embers were carried across Kananaskis Valley a distance of 3 1/2 miles starting a fire 2 miles south of Boundary Cabin.... by 6 p.m. the Kananaskis Valley was all on fire for a distance of 6 miles along [long?] by three miles wide." (Alberta Forest Service 1936a).

P. Campbell's description indicates that gale-force winds

caused the fire to spot over long distances and to have a rapid rate of spread. This fire was beyond the control of those forces used in 1936, and probably even by present improved fire control methods unless an early initial attack is successful. Major fires in Kananaskis Provincial Park under similar weather conditions might have similar fire behavior (long-range spotting and crowning), which would make fire containment difficult except when the fire was small. The characteristic fire size and behavior of major fires in Kananaskis Provincial Park should be considered when planning the location and type of facilities to be constructed in the lower elevational (<2000 m) areas of Kananaskis Provincial Park, and in developing initial attack plans.

D. Burn Direction and Fuel Breaks

Strong dry summer winds from the south and west during July and August seemed to be a critical factor in the behavior of fires in the Kananaskis Valley. The 1920, 1890 and 1803 fires (Figures 9, 10 and 14) appear to have burned in a northerly direction as indicated by fire scars and prevailing wind patterns. The 1858 fire might have come north over the Elk Valley via Elk Pass and then continued to burn north, driven by the normal prevailing winds. The 1920, 1890, and 1858 fires have burned up the slope of Mt. Wintour, which has a southwesterly exposure indicating that topography has also a strong effect on burn direction. The

Lower Kananaskis River appeared to have acted as a fire break for the 1920 fire but not for the 1890 and 1858 fires, perhaps because of differences in wind direction or fire intensity. Burn direction and fire size may also have been influenced by changes in weather conditions, stand composition and density, and moisture regime differences due to elevation.

The characteristic burn direction of fires in Kananaskis should be considered if fuel breaks are constructed around facilities. Sando (1978) discussed the usefulness of fuels management[1] in a fire regime similar to that experienced in Kananaskis Provincial Park (infrequent fires of high intensity):

> "The occurrence of periodic droughts in this regime makes the need for fuels management highly variable in time; the unusual severity of fire behavior that accompanies these droughts precludes the general usefulness of fuels management. Certainly there are opportunities to use fuels management for specific high risk fuels such as slash; however, fire behavior in the fuels found in this regime can reach such high levels of intensity under severe weather conditions that most fuel types are capable of supporting fires beyond our current control capability." (Sando 1978).

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[1] Major methods: change intensity potential and development of fuel breaks or barriers to fire spread.

This describes extreme cases which are not necessarily characteristic of all fires or sections of fires in Kananaskis Provincial Park. Fuel breaks could be effective in controlling the direction of burn if used as a burn-out line, or keeping fires within campground areas where ignition has occurred; but the limitations of fuels management must be recognized.

E. Mean Fire Return Intervals

Many fire history studies have presented M.F.R.I. on the basis of the study area (Heinselman 1973, Cwynar 1977, Sneck 1977 and Tande 1977). Comparison of this M.F.R.I. for Kananaskis Provincial Park with other results is of little value, because the M.F.R.I. varies with the size of the study area.

A more useful comparison would be similar to that used in the review of fire history studies in the Northern Rockies by Arno (1978b). All stands were divided into blocks of 41-81 ha (100-200 acres) and identified by forest series or ecological zone. The M.F.R.I. was then calculated for each of these stands. Arno (1978b) acknowledged that M.F.R.I. at any given point within a stand would normally be somewhat longer. This was not found in Kananaskis Provincial Park, because fires were larger and occurred at longer intervals than those described by Arno (1978b).

The elevational classes used in testing difference in M.F.R.I. for aspect and elevation closely followed the

limits for the lower and upper subalpine zones of the *Abies lasiocarpa* series described by Pfister *et al.* (1977) (Steve Arno, pers. comm. 1978c). A comparison of M.F.R.I. in Kananaskis Provincial Park and in other areas of the Northern Rockies showed some similarities:

	Lower Subalpine Zone M.F.R.I.	Upper Subalpine Zone M.F.R.I.
Kananaskis Provincial Park, Alberta	90	153
Jasper National Park, Alberta (Tande 1977)	--	74
Coram Experimental Forest, Montana (Sneck 1977)	130	>150
Bitterroot Valley, Montana (Arno 1976)		
South	--	32
North	--	41

Arno (1978b) felt the shorter M.F.R.I.'s for the Bitterroot Valley and Jasper National Park (Tande 1977) were due to the presence of drier slopes than in Kananaskis and Coram Experimental Forest.

Tande (1977) expressed concern over the time period for which M.F.R.I. estimates are valid. Long-term fluctuations in climate may have an effect on the quantity and flammability of the available organic material, and consequently the frequency, intensity and areal extent of fires (Tande 1977). The presence of two isolated Douglas-fir stands in Kananaskis Provincial Park might indicate the

climate was warmer and drier sometime in the past, with more extensive areas cf montane type forests (and corresponding shorter M.F.R.I.). Keen (1937) examined climatic cycles in eastern Oregon as indicated by dendroclimatology and found the drought of 1917-1931 was the most intense and prolonged in 650 years. This indicates that the time between periods of intense and prolonged droughts may be long. The cluster of major fires between 1890 and 1920 might be due to a warmer, drier climatic period and more human travel through the Kananaskis area, as was indicated for Banff (Byrne 1968).

The longest interval between major fires between 1712 and 1920 was 38 years. This indicates that weather conditions favourable for extensive burning in Kananaskis Provincial Park do not occur only at extremely long intervals. The M.F.R.I.'s listed in this study are reasonably valid for the period of investigation (1712-1920). The time period (58 years) since the last major fire in Kananaskis Provincial Park is longer than the longest period between major fires listed above. The actual effect of fire suppression efforts since the 1940's on the occurrence of major fires in Kananaskis Provincial Park was difficult to determine because of the following factors:

1. Weather conditions since fire suppression was initiated may not have been favourable for extensive burning (long-term weather records are not available) in Kananaskis Provincial Park.

2. If weather conditions had been favourable for extensive burning, an ignition source may not have been present.
3. It is not known whether the 1933, 1967, and/or 1973 fires might have been larger than 1000 ha if fire suppression had not been carried out.

F. Fire Occurrence and Climate

Tande (1977) concluded that climate was the major environmental factor controlling the frequency and extent of past forest fires. This conclusion was based on the correlation between fire years and a dendroclimatic record for Jasper National Park. A good correlation was found between fire years in Kananaskis Provincial Park and a maximum latewood density chronology for Peyto Lake, Alberta. This indicates that climate was the major environmental factor in the occurrence of fires in Kananaskis Provincial Park, although local variations in weather, fuel conditions (loading, arrangement, continuity and fuel moisture) and topography would determine the final areal extent of the burns.

G. Implications for Fire Management

The "natural" fire regime of Kananaskis Provincial Park before 1920 was that of large (>1000 ha) fires with medium to high fire intensity at infrequent intervals. Small fires have occurred, but their total overall stand disturbance was

less than only one major fire in Kananaskis. Development of recreation facilities in the Lower Kananaskis Valley of Kananaskis Provincial Park has led to a policy of total suppression on all fires.

Fire has played a key role in the development and renewal of forest stands in Kananaskis Provincial Park. It is important to be aware of the consequences of fire exclusion on plant succession and to consider alternate methods, such as prescribed burning or selective removal of trees, to simulate the effects of past fires to meet park management objectives, should this be judged appropriate. Some of the consequences of fire exclusion (Heinselman 1975), which apply to Kananaskis Provincial Park are:

1. Aging of many forest stands beyond which might not otherwise have occurred.
2. Progression of successional changes in some forests beyond which might not otherwise have occurred.
3. Failure of stand regeneration due to lack of fire (little regeneration has occurred since 1920).
4. Changes in nutrient cycles, dry matter accumulation and energy flows.
5. Changes in production of herbage and browse for wildlife.

VIII. RESULTS - FUEL APPRAISAL

A. Fuel Types

Thirteen fuel types were identified in Kananaskis Provincial Park (Table 5). Photographs of a representative stand for each fuel type are presented in Appendix 1. A description of each fuel type is presented in Table 5. The areal extent of fuel types in Kananaskis Provincial Park is illustrated on the fuel type maps (Figures 22 to 25 and Appendix 6, attached pocket).

B. Fuel Loading

Dead and Down Fuels

Fine fuel loading in all three size classes showed significant differences among fuel types (Appendix 3). Table 6 illustrates that fine fuel loading in the (>0≤.64 cm) size class ranged from .15 to .76 t/ha. Fine fuel loading in the (>.64≤2.5 cm) size class ranged from .29 to 3.16 t/ha. Fine fuel loading in the (>2.5≤7.6 cm) size class ranged from 1.49 to 7.65 t/ha. A multiple comparison of the fine fuel loading (>0≤.64 cm) means showed that a difference of ≥.33 t/ha between fuel types was significant. A multiple comparison of the fine fuel loading (>.64≤2.5 cm) means showed that a difference of ≥1.47 t/ha between fuel types was significant. A multiple comparison of the fine fuel loading (>2.5≤7.6 cm) means showed that a difference of ≥4.04t/ha between fuel types was significant.

Table 5. Description of fuel types.

Fuel Type	Description
1	1920 origin lodgepole pine with an open appearance, little dead and down material and a well developed shrub layer.
1A	1920 origin lodgepole pine with an open appearance, much dead and down material and a well developed shrub layer.
2	1920, 1904 and 1890 origin lodgepole pine with a dense appearance, medium amount of dead and down material and a poorly developed shrub layer.
3	1890 and 1858 origin lodgepole pine with a medium tree density, with little dead and down material, most stands show thinning by fire, no spruce/fir understory (ie. no ladder fuels).
4	150 to 300 year old lodgepole pine, transition stand to old growth, a good component of spruce in the overstory and much dead and down material.
5	1904, 1890 and 1858 origin lodgepole pine with a medium tree density, medium amount of dead and down material and spruce/fir understory (ie. ladder fuels).
6	1904 and 1858 origin lodgepole pine with an open stand appearance, dominated by spruce and fir in the overstory.
7	300+ year old spruce with dead lodgepole pine in the overstory and much dead and down material.
8	Bogs and fens.
9	Recent burns (1967 and 1973)
10	300+ year old spruce/fir/alpine larch complex at high elevation.
11	Partial cut areas (not sampled).
12	Clearcuts (not sampled).

FUEL TYPE

KEY

Fuel Type	Description	Initial Rate of Spread (IRS)	Fire Intensity (FI)	Crowning Potential (CP)	Resistance to Control	Overall Fire Hazard
1	1920 ORIGIN LODGEPOLE PINE WITH AN OPEN APPEARANCE, LITTLE DEAD AND DOWN MATERIAL AND A WELL DEVELOPED SHRUB LAYER.	L	L	L	M	$L^{IRS,FI,CP}$
1A	1920 ORIGIN LODGEPOLE PINE WITH AN OPEN APPEARANCE, MUCH DEAD AND DOWN MATERIAL AND A WELL DEVELOPED SHRUB LAYER.	H	H	L	H	$H^{IRS,FI}$
2	1920, 1904 AND 1890 ORIGIN LODGEPOLE PINE WITH A DENSE APPEARANCE, MEDIUM AMOUNT OF DEAD AND DOWN MATERIAL AND A POORLY DEVELOPED SHRUB LAYER.	H	M	M	H	H^{IRS}
3	1890 AND 1858 ORIGIN LODGEPOLE PINE WITH A MEDIUM TREE DENSITY, WITH LITTLE DEAD AND DOWN MATERIAL, MOST STANDS SHOW THINNING BY FIRE, NO SPRUCE/FIR UNDERSTORY (IE. LADDER FUELS).	M	L	M	M	$M^{IRS,CP}$
4	150 TO 300 YEAR OLD LODGEPOLE PINE, TRANSITION STAND TO OLD GROWTH, A GOOD COMPONENT OF SPRUCE IN THE OVERSTORY AND MUCH DEAD AND DOWN MATERIAL.	H	M	M	H	H^{IRS}
5	1904, 1890 AND 1858 ORIGIN LODGEPOLE PINE WITH A MEDIUM TREE DENSITY, MEDIUM AMOUNT OF DEAD AND DOWN MATERIAL AND SPRUCE/FIR UNDERSTORY (IE. LADDER FUELS).	M	H	H	H	$H^{FI,CP}$
6	1904 AND 1858 ORIGIN LODGEPOLE PINE WITH AN OPEN STAND APPEARANCE, DOMINATED BY SPRUCE AND FIR IN THE OVERSTORY.	L	M	M	M	$M^{FI,CP}$
7	300+ YEAR OLD SPRUCE WITH DEAD LODGEPOLE PINE IN THE OVERSTORY AND MUCH DEAD AND DOWN MATERIAL.	H	H	M	H	$H^{IRS,FI}$
8	BOGS AND FENS.					
9	RECENT BURNS (1967 AND 1973)	L	M	L	L	M^{FI}
10	300+ YEAR OLD SPRUCE/FIR/ALPINE LARCH COMPLEX AT HIGH ELEVATION.	L	L	M	L	M^{CP}
11	PARTIAL CUT AREAS (NOT SAMPLED).					
12	CLEARCUTS (NOT SAMPLED)					

L = LOW M = MODERATE H = HIGH

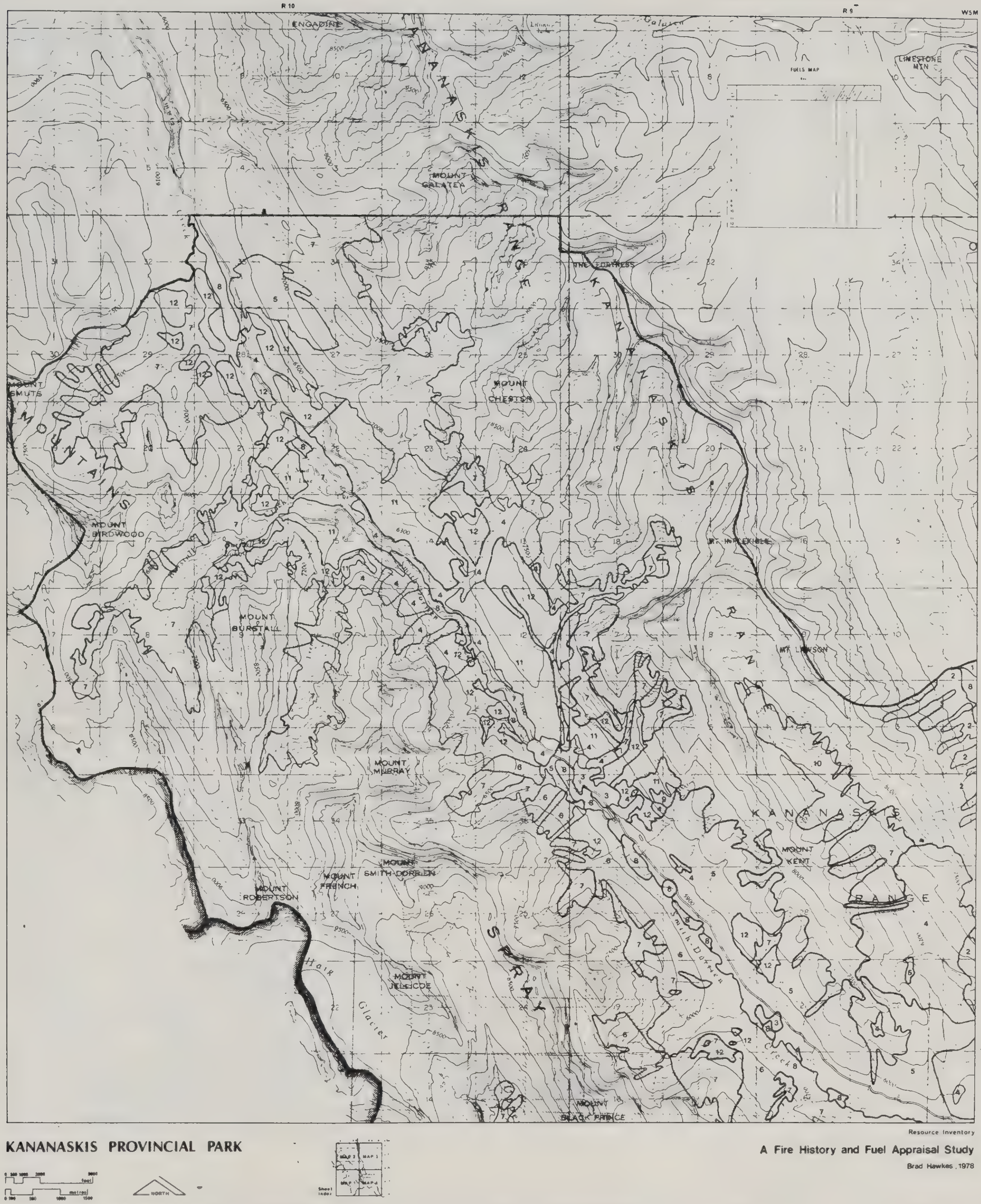

Figure 22. Fuel type map. Part I

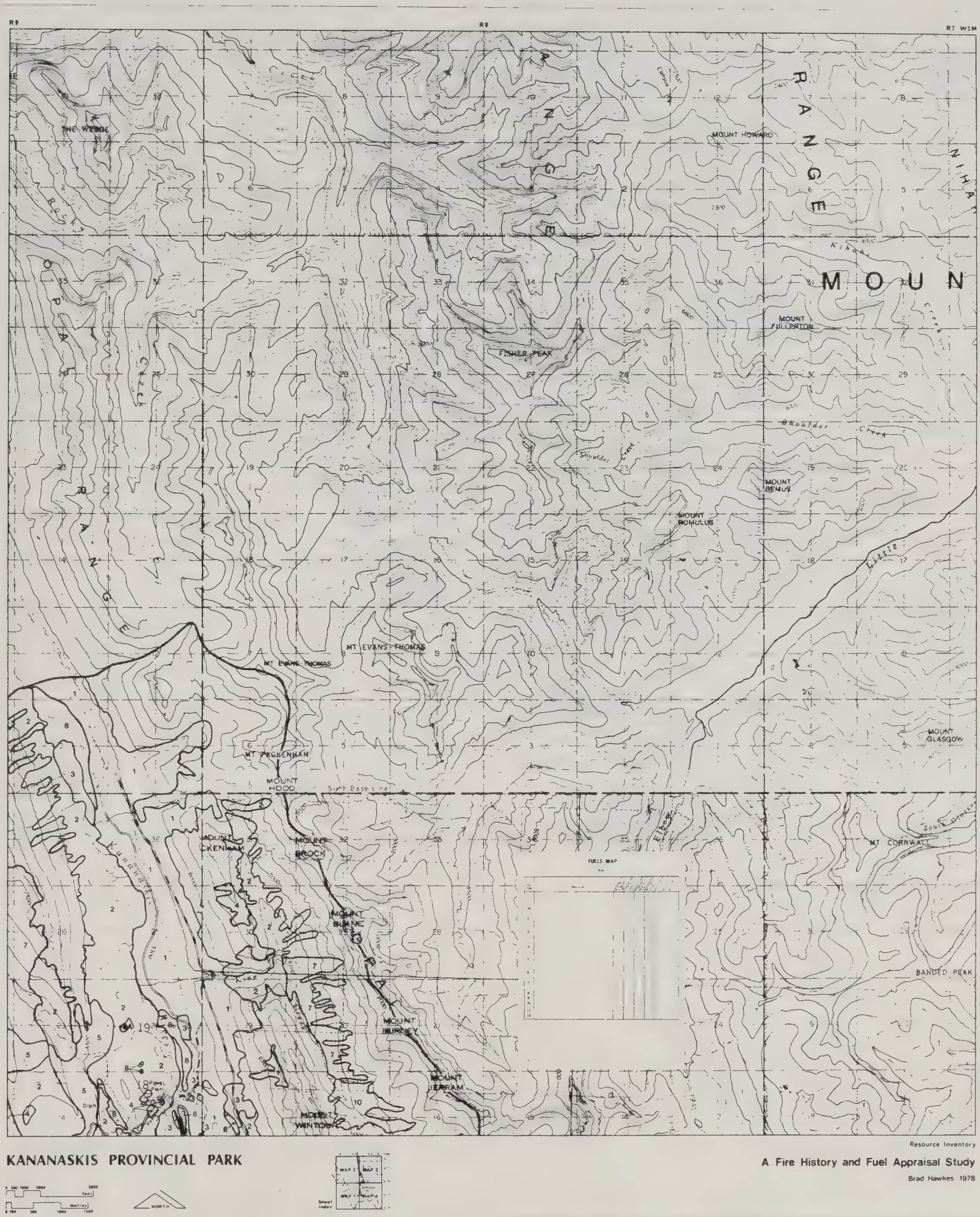

Figure 23. Fuel type map. Part II

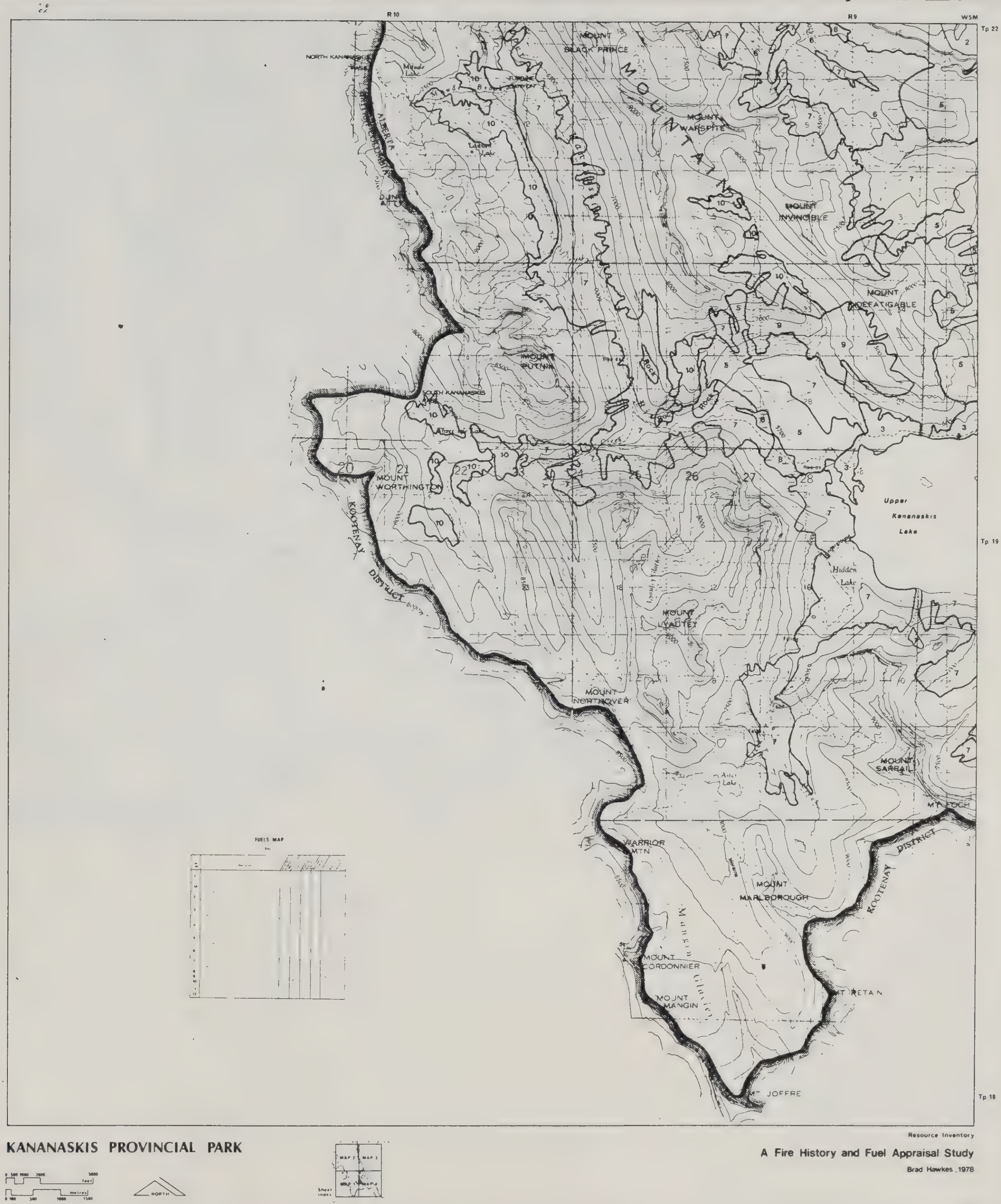

Figure 24. Fuel type map. Part III

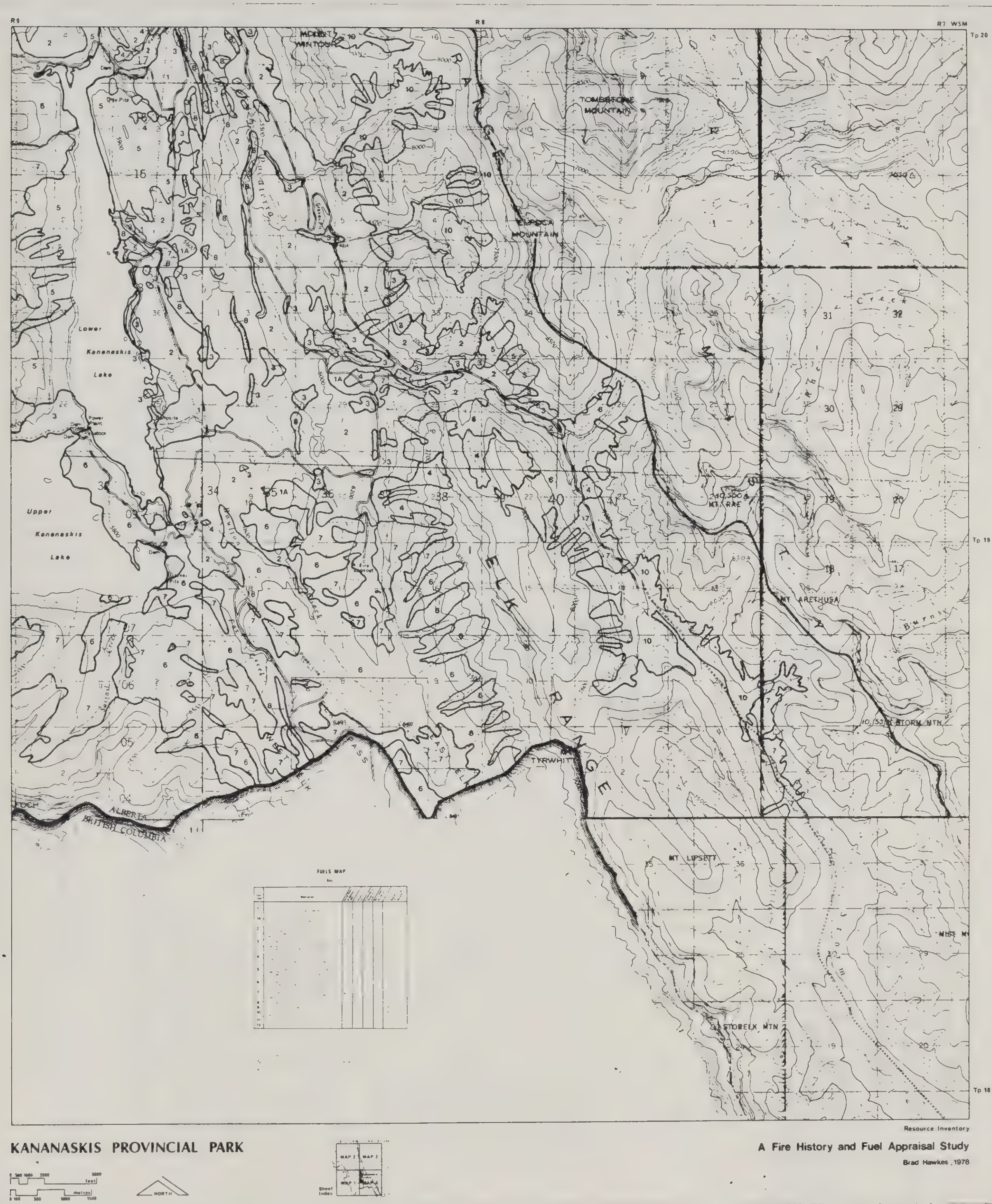

Figure 25. Fuel type map. Part IV

Table 6. Dead and down fuel loading of fuel types in Kananaskis Provincial Park.

Fuel Type	Fine Fuel Loading (t/ha) $>0\leq0.64$cm[2]	$>0.64\leq2.5$cm[2]	$>2.5\leq7.6$cm[3]	Coarse Fuel Loading (t/ha) Rotten[4] >7.6cm	Sound[3] >7.6cm	Total >7.6cm	Total All Size Classes (t/ha)	Fuel Depth (cm)
1	0.15[a] [1]	1.02[ab]	1.75[a]	17.35[ab]	1.08[a]	18.43[a]	21.35[a]	3.24[a]
1A	0.18[a]	3.18[c]	6.71[b]	123.14[e]	17.62[b]	140.76[d]	150.83[d]	23.37[e]
2	0.50[bcd]	2.84[c]	7.65[b]	45.63[cd]	0.55[a]	46.18[b]	57.17[b]	7.50[ab]
3	0.58[cd]	2.42[bc]	7.01[b]	3.06[a]	5.42[ab]	8.48[a]	18.49[a]	5.84[ab]
4	0.51[bcd]	2.62[c]	7.46[b]	28.33[bc]	33.44[c]	61.77[b]	72.36[b]	14.48[cd]
5	0.34[abc]	1.72[abc]	2.25[a]	101.11[e]	3.03[ab]	104.14[c]	108.45[c]	10.00[bc]
6	0.24[ab]	0.71[a]	1.49[a]	66.74[d]	2.48[ab]	69.22[b]	71.66[b]	4.30[a]
7	0.76[d]	3.16[c]	1.96[a]	48.01[cd]	52.07[d]	100.08[c]	105.96[c]	16.28[d]
9	0.34[abc]	0.69[a]	2.58[a]	18.70[ab]	36.24[cd]	54.94[b]	58.55[b]	13.36[cd]
10	0.33[abc]	0.29[a]	1.83[a]	6.44[a]	4.00[ab]	10.44[a]	12.89[a]	3.74[a]

[1] Means with the same letter are not significantly different at the 5% level of probability by Scheffé's multiple comparison (Scheffé 1959). Means without the same letter are significantly different. This comparison is between fuel types.

[2] Specific gravity used was .48

[3] Specific gravity used was .40

[4] Specific gravity used was .30

Both sound and rotten coarse fuel loading showed significant differences among fuel types (Appendix 3). Table 6 illustrates that sound coarse fuel loading ranged from .55 to 52.07 t/ha. Rotten coarse fuel loading ranged from 3.06 to 123.14 t/ha. A multiple comparison of sound coarse (>7.6 cm) loading means showed that a difference of ≥15.56 t/ha between fuel types was significant. A multiple comparison of rotten coarse (>7.6 cm) loading means showed that a difference of ≥22.09 t/ha between fuel types was significant.

Table 6 illustrates that total coarse fuel loading (>7.6 cm, sound and rotten) ranged from 8.48 to 140.76 t/ha. Total coarse loading showed significant differences among fuel types (Appendix 3). A multiple comparison of the total loading means showed that a difference of ≤27.61 t/ha between fuel types was significant.

Table 6 illustrates that total dead and down loading (all size classes) ranged from 12.89 to 150.83 t/ha. Total dead and down loading showed significant differences among fuel types (Appendix 3). A multiple comparison of total dead and down fuel loading means showed that a difference of ≤28.47 t/ha between fuel types was significant.

Fuel depth varied significantly among fuel types (Appendix 3). Table 6 illustrates that fuel depths ranged from 3.2 to 23.4 cm. A multiple comparison of the means indicated that a difference of ≥5.7 cm in fuel depth between fuel types was significant.

Humus and Moss Biomass

Humus biomass varied significantly among fuel types (Appendix 3). Table 7 illustrates that humus biomass estimates ranged from 16.89 to 129.25 t/ha. Humus depth ranged from 2.7 to 10.3 cm. A multiple comparison of the means indicated that a difference of ≥66.30 t/ha in humus biomass between fuel types was significant. Large variations in humus depth were found within each fuel type (Table 7).

Moss biomass varied significantly among fuel types (Appendix 3). Table 7 illustrates that moss biomass estimates ranged from 0.24 to 8.50 t/ha. Moss biomass was low in young (60 years) stands (fuel types 1, 1A, 2 and 9) and in the spruce/fir/alpine larch stands at high elevation (fuel type 10). A multiple comparison of the means indicated that a difference of ≥1.76 t/ha in moss biomass between fuel types was significant. Moss depth ranged from .7 to 6.3 cm and percent cover from 22 to 91%. Large variation in moss depth and cover was found within fuel types where coverage was spotty (Table 7).

Shrub and Herb Biomass

Shrub biomass varied significantly among fuel types (Appendix 3). Table 8 illustrates that shrub biomass ranged from .25 to 7.25 t/ha. A multiple comparison of the means indicated that only fuel type 1 was significantly different because of the high variability in biomass between plots within a fuel type.

Shrub height varied significantly among fuel types

Table 7. Humus and moss biomass of fuel types in Kananaskis Provincial Park.

Fuel Type	Humus[3] Biomass (t/ha)	Humus Depth (cm)	Moss Biomass (t/ha)	Moss Depth (cm)	Moss Percent Cover (%)
1	16.89[a][1]	2.7(1.7)[2]	1.71[ab]	3.3(1.4)	30(22)
1A	48.50[ab]	7.1(5.1)	1.88[ab]	3.3(0.8)	35(29)
2	29.73[a]	4.6(3.0)	1.87[ab]	2.5(1.2)	41(25)
3	45.24[ab]	4.6(4.3)	3.18[bc]	3.3(1.0)	61(16)
4	71.98[abc]	8.5(4.1)	8.50[c]	6.1(1.4)	91(4)
5	111.47[bc]	10.3(4.9)	6.80[c]	5.7(1.5)	78(18)
6	77.59[abc]	6.6(5.4)	4.77[b]	4.1(1.4)	74(17)
7	129.25[c]	10.1(5.0)	8.44[c]	6.3(1.3)	88(11)
8	-	-	3.46[bc]	4.5(1.8)	46(12)
9	28.98[a]	3.5(4.3)	0.24[a]	0.7(0.3)	22(22)
10	17.95[a]	2.9(1.5)	0.47[a]	1.0(0.9)	23(23)

[1] Means with the same letter are not significantly different at the 5% level of probability by Scheffé's multiple comparison (Scheffé 1959). Means without the same letter are significantly different. This comparison is between fuel types.

[2] Standard deviation in brackets.

[3] Humus is all organic matter below moss.

Table 8. Shrub and herb biomass of fuel types in Kananaskis Provincial Park.

Fuel Type	Shrub Biomass (t/ha)	Shrub Height (m)	Herb Biomass (t/ha)
1	7.25^{b}[1]	1.08^{de}	0.31^{bc}
1A	2.17^{a}	0.86^{cd}	0.13^{ab}
2	0.46^{a}	0.60^{b}	0.11^{ab}
3	0.89^{a}	0.91^{d}	0.28^{bc}
4	1.86^{a}	0.57^{b}	0.05^{a}
5	1.50^{a}	0.89^{d}	0.12^{ab}
6	3.96^{a}	1.29^{e}	0.03^{a}
7	1.49^{a}	0.96^{d}	0.02^{a}
8	2.84^{a}	0.62^{bc}	0.55^{d}
9	0.25^{a}	0.24^{a}	0.41^{bc}
10	1.02^{a}	0.17^{a}	0.04^{a}

[1] Means with the same letter are not significantly different at the 5% level of probability by Scheffé's multiple comparison (Scheffé 1959). Means without the same letter are significantly different. This comparison is between fuel types.

(Appendix 3). Table 8 illustrates that shrub height ranged from .17 to 1.29 metres. A multiple comparison of the means indicated that a difference of ≥.26 m in shrub height between fuel types was significant.

Herb biomass varied significantly among fuel types (Appendix 3). Table 8 illustrates that herb biomass ranged from .02 to .55 t/ha. In general, herb biomass was less in stands over 200 years old than in younger stands. The large herb biomass in Type 8 (bogs and ferns) was due to the abundance of sedge (*Carex* sp.). The abundance of fireweed (*Epilobium* sp.) in Type 9 (recent burns) accounts for the high herb biomass. A multiple comparison of the means indicated that a difference of ≥.20 t/ha in herb biomass between fuel types was significant.

Crown Biomass

Crown biomass varied significantly among fuel types (Appendix 3). Table 9 illustrates that crown biomass ranged from 18.93 to 51.34 t/ha. Low crown biomass occurred in young stands where crowns were small and in old-growth stands where crowns were large, but the number of trees/ha was low. High crown biomass occurred in middle aged (i.e. 100-200 years) stands where crown size and trees/ha were maximized. A multiple comparison of the means indicated that a difference of ≥12.61 t/ha in crown biomass between fuel types was significant. Crown biomass was not used to assist in rating fire intensity, because surface fires only were considered. Crown biomass would affect fire intensity and

Table 9. Crown biomass and stand composition of fuel types in Kananaskis Provincial Park.

Fuel Type	Pine	Stand Composition (%) Spruce	Subalpine Fir	Alpine Larch	Snags	Total Trees/ha	Total Crown Biomass (t/ha)
1	88	11	1	-	-	3012	18.93[a] [1]
1A	61	34	3	-	2	4521	25.03[ab]
2	82	-	-	-	18	15346	25.89[ab]
3	90	-	-	-	10	5523	37.17[bc]
4	41	35	14	-	10	2361	51.34[d]
5	51	24	7	-	18	5318	45.23[cd]
6	6	34	59	-	1	1194	26.96[ab]
7	-	42	37	-	21	750	23.76[a]
10	-	23	66	7	4	2350	44.83[cd]

[1] Means with the same letter are not significantly different at the 5% level of probability by Scheffé's multiple comparison (Scheffé 1959). Means without the same letter are significantly different. This comparison is between fuel types.

rate of spread if crowning occurred.

C. Crowning Potential

Crowning potential varied significantly among fuel types (Appendix 3). Table 10 illustrates that crowning potential ranged from 2.6 to 7.3. Fuel type 5 had the greatest crowning potential (7.3) because spruce and fir regeneration in the understory could act as ladder fuels. Fuel types 1A and 1 had the lowest crowning potential because of their discontinuous canopies. The likelihood of crowning was probably underestimated for fuel type 1A with high dead and down loading; because the key does not take into account fuels on the ground, which contribute to crown fire development. Fuel type 2 had a moderate crowning potential because of the continuous crowns of the young lodgepole pine. A multiple comparison of the means indicated that a difference of ≥ 1.4 in crowning potential between fuel types was significant.

D. Resistance to Control

Resistance to control varied significantly among fuel types (Appendix 3). Table 10 illustrates that resistance to control ranged from 7.3 to 27.0 metres/45 min.-hour/man. The low resistance to control of fuel types 1, 9 and 10 was the result of the low dead and down loading, trees/ha and humus depth. The high resistance to control of fuel types 1A, 2, 4, 5 and 7 reflect the high dead and down loading, increased

Table 10. Crowning potential and resistance to control using handtools of fuel types in Kananaskis Provincial Park.

Fuel Type	Crowning Potential (relative scale, 0-10)	Resistance to Control (m/45 min. hour/man)
1	3.5[b] [1]	19.2[cd]
1A	3.4[ab]	8.5[a]
2	6.3[ef]	10.4[a]
3	5.8[cde]	16.1[bc]
4	4.8[cd]	8.0[a]
5	7.3[f]	7.3[a]
6	5.7[cde]	12.1[b]
7	5.9[def]	9.6[a]
9	2.6[a]	27.0[e]
10	4.5[bc]	22.5[de]

[1] Means with the same letter are not significantly different at the 5% level of probability by Scheffé's multiple comparison (Scheffé 1959). Means without the same letter are significantly different. This comparison is between fuel types.

humus depth and greater number of trees/ha in type 2. A multiple comparison of the means indicated that a difference of ≥5.0 metres/45min.-hour/man in resistance to control between fuel types was significant.

Table 11 illustrates the class values used to rate fuel types for resistance to control. Fuel types were rated low if resistance to control was ≥20 m/45 min.-hour/man, moderate for <20≥10 m/45 min.-hour/man and high for <10 m/45 min.-hour/man.

Table 12 illustrates the resistance to control ratings for fuel types in Kananaskis Provincial Park (Type 8 - bogs and fens not included). Fuel types 9 and 10 had a low resistance to control. Fuel types 1, 3 and 6 had a moderate resistance to control, while fuel types 1A, 2, 4, 5 and 7 were rated as having high resistance to control.

E. Fire Hazard Ratings

Initial Rate of Spread

Table 11 illustrates the class values used to rate fuel types for initial rate of spread. Fuel types were rated low if fine fuel loading (<2.5 cm) was <2 t/ha, moderate for ≥2<3 t/ha and high for ≥3 t/ha. The class values were based on the grouping of fine fuel loading of fuel types, as indicated by the multiple comparison test results.

Table 12 illustrates the initial rate of spread ratings for fuel types in Kananaskis Provincial Park (type 8 - bogs and fens not included). Fuel types 1, 6, 9 and 10 had a low

Table 11. Class values for fire hazard ratings and resistance to control.

Fire Hazard Ratings		Class Values	
	Low	Moderate	High
Initial Rate of Spread Fine Fuel Loading ($\leq$2.54 cm) (t/ha)	<2	$\geq$2 <3	$\geq$3
Fire Intensity Available Dead and Down Loading (t/ha)	<16	$\geq$16 <40	$\geq$40
Crowning Potential Scale (0-10)	<4	$\geq$4 <7	$\geq$7
Resistance to Control (m/45 min. hour/man)	$\geq$20	<20 $\geq$10	<10

Table 12. Fire hazard and resistance to control (using handtools) ratings for fuel types in Kananaskis Provincial Park.

Fuel Type	Initial Rate of Spread[1] (irs)	Fire Intensity[1] (fi)	Crowning Potential[2] (cp)	Resistance to Control[3]	Overall Fire Hazard[4]
1	LOW	LOW	LOW	MOD.	LOW^{irs,fi,cp}
1A	HIGH	HIGH	LOW	HIGH	HIGH^{irs,fi}
2	HIGH	MOD.	MOD.	HIGH	HIGH^{irs}
3	MOD.	LOW	MOD.	MOD.	MOD.^{irs,cp}
4	HIGH	MOD.	MOD.	HIGH	HIGH^{irs}
5	MOD.	HIGH	HIGH	HIGH	HIGH^{fi,cp}
6	LOW	MOD.	MOD.	MOD.	MOD.^{fi,cp}
7	HIGH	HIGH	MOD.	HIGH	HIGH^{irs,fi}
9	LOW	MOD.	LOW	LOW	MOD.^{fi}
10	LOW	LOW	MOD.	LOW	MOD.^{cp}

1 see results section for class values and methods section for estimation procedure.

2 based on Fahnestock (1970) key (class values in results section).

3 based on Murphy and Quintilio (1978) fire line construction rates using handtools (class values in results section).

4 based on highest rating for initial rate of spread, fire intensity or crowning potential.

initial rate of spread rating. Fuel type 6 might have had a moderate rating if the shrub layer was considered because of the extensive cover of *Menziesia ferruginea*, thought to be relatively flammable under low fuel moisture conditions (Dennis Dube, pers. comm. 1978). Fuel types 3 and 5 had a moderate rating, while 1A, 2, 4 and 7 had a high rating for initial rate of spread.

Fire Intensity

Table 11 illustrates the class values used to rate fuel types for fire intensity. Fuel types were rated low if available dead and down loading was <16 t/ha, moderate for ≥16<40 t/ha and high for ≥40 t/ha. The class values were based on the grouping of dead and down fuel loading (all size classes) of fuel types, indicated by the multiple comparison test results.

Table 12 illustrates the fire intensity ratings for fuel types in Kananaskis Provincial Park (Type 8 - bogs and fens not included). Fuel types 1, 3 and 10 had a low fire intensity rating. Fuel types 2, 4, 6 and 9 had a moderate rating, while 1A, 5 and 7 had a high rating for fire intensity.

Crowning Potential

Table 11 illustrates the class values used to rate fuel types for crowning potential. The class values correspond to those established by Fahnestock (1976). Fuel types were rated low if crowning potential was <4, moderate for ≥4<7 and high for ≥7.

Table 12 illustrates the crowning potential ratings for fuel types in Kananaskis Provincial Park (Type 8 - bogs and fens not included). Fuel types 1, 1A and 9 had a low crowning potential. Fuel types 2, 3, 4, 6, 7 and 10 had a moderate rating, while Type 5 had a high rating for crowning potential.

Overall Fire Hazard

Table 12 illustrates the overall fire hazard rating for fuel types in Kananaskis Provincial Park (Type 8, bogs and fens not included). Only fuel type 1 had an overall low fire hazard. Fuel types 3, 6, 9 and 10 had a moderate rating, while types 1A, 2, 4, 5 and 7 were rated high.

F. Fuel Type Map

The fuel type map illustrates the areal extent and location of fuel types in Kananaskis Provincial Park (Figures 22 to 25 and Appendix 6, attached pocket). Fuel types 1, 1A, 2 and 3 are found primarily in the Lower Kananaskis Valley, east of Lower Kananaskis Lake. This area is where most of the Park facilities are or will be located (Melanie Miller, pers. comm. 1978). Fuel types 4, 5 and 6 are found primarily in the Elk Pass area and the Smith-Dorrien Valley. Fuel type 7 is found throughout the Park, primarily at elevations above 1800 metres. Fuel type 8 is found throughout the Park. Fuel type 9 is found in one location in the Smith-Dorrien Valley and another near Upper Kananaskis Lake. Fuel type 10 is found only at high

elevation (usually above 2100 m) throughout the Park. Fuel types 11 and 12 which were not sampled are found only in the Smith-Dorrien Valley.

Table 13 illustrates that the fuel type areas ranged from 83 to 6896 ha in size (0.4 to 30.3% of the total forested area). Fuel type 7 is the most extensive in area followed by fuel type 2. Fuel type 2 covers most of the area east of Lower Kananaskis Lake. Fuel type 1A has the smallest area but is important because a major campground (Elkwood) has been partially located within this fuel type. Table 13 illustrates that 65% of the forested area had a high overall fire hazard, 21% had a moderate hazard, 5.4% had a low hazard and 8.6% was not rated.

G. Lightning and Man-Caused Risk

Table 14 illustrates that between 1932 - 1977, 21 class A fires (<.1 ha), 6 class B fires (≥.1<4.1 ha), 1 class D fire (≥40.5<203 ha) and 2 class E fires (≥203 ha) were reported within Kananaskis Provincial Park. The establishment of Kananaskis Fire Lookout in 1953 increased the number of reported fires (especially lightning caused). Only 1 lightning fire was reported in the 30 year period before 1963, while 5 were reported from 1963 to 1977. Out of the 5 man-caused fires before 1959, four were associated with clearing operations for the two hydro-electric dams and the forestry trunk road (Table 14).

Because of the limited fire detection and reporting

Table 13. Areas and percent of total forested area of fuel types in Kananaskis Provincial Park and areas of overall fire hazard ratings.

Fuel Type	Overall Fire Hazard Rating	Area (ha)	Percent of Total Forested Area (%)
1	LOW	1231	5.4
1A	HIGH	83	0.4
2	HIGH	3889	17.1
3	MOD.	608	2.7
4	HIGH	1052	4.6
5	HIGH	2886	12.7
6	MOD.	2830	12.4
7	HIGH	6896	30.3
8		460	2.0
9	MOD.	267	1.2
10	MOD.	1093	4.8
11		829	3.7
12		610	2.7
Summary			
	LOW	1231	5.4
	MOD.	4798	21.0
	HIGH	14806	65.0
	Not Rated	1899	8.6

Table 14. Summary of fire occurrence in Kananaskis Provincial Park (1932-1977) from Alberta Forest Service fire records.

Year	No. of Fires* by Class	Total No. of Fires	Cause			Area Burned (ha)		
			Man	Lightning	Unknown	Man	Lightning	Unknown
1932	A=1	1		1			Neg.	
1933**	E=1	1	1			583.0		
1934**	B=1	1	1			2.0		
1935**	B=1	1	1			0.2		
1949**	B=2	2	2			4.9		
1955	B=1	1	1			0.6		
1959	A=3	3	3			0.1		
1960	A=2	2	2			0.1		
1962	A=3	4	3		1	Neg.		
	B=1							0.4
1963	A=1	1		1			Neg.	
1967	E=1	1		1			233	
1969	A=2	2	1	1		Neg.	Neg.	
1970	A=1	1	1			Neg.		
1971	A=1	1	1			Neg.		
1972	A=2	2	1	1		Neg.	Neg.	
1973	A=1	2	1	1		Neg.		
	D=1						49	
1974	A=2	2	1		1	Neg.		Neg.
1975	A=1	1	1			Neg.		
1976	A=1	1	1			Neg.		
Totals	A=21 B=6 D=1 E=2	30	22	6	2	591	282	0.4

* Class A fire - <0.1 ha; Class B fire - $\geq$0.1 <4.1 ha; Class C fire - $\geq$4.1 <40.5 ha; Class D fire - $\geq$40.5 <203 ha; Class E fire $\geq$203 ha

** Fires caused by clearing operations for the two dams and the forestry trunk road

before 1959, the period 1959 to 1977 was used to discuss lightning and man-caused fire risk for Kananaskis Provincial Park. On the average, less than 1 man-caused fire per year (.84 fires/year or 1 every 1.2 years), of which none exceeded .1 ha in size, was reported. An average of .26 lightning fires, of which two exceeded class C fire size (≥40.5 ha), occurred each year (or 1 every 3.8 years).

Harvey (1979) reported the average number of days for each summer month that lightning was observed from Kananaskis Fire Lookout to be as follows: .5 days in May, 1.8 days in June, 1.7 days in July, 3.0 days in August, and .5 days in September. A comparison of this information and that in Table 14 indicates that many of the lightning strikes in Kananaskis Provincial Park occurred when weather conditions were not suitable for fire ignition and spread.

Many of the man-caused fires have occurred around campgrounds and along roadways (Figure 26). A distinct lightning fire location pattern was not evident from Figure 26, although this may be due to the low number of reported fires, especially from remote areas, such as the Upper Kananaskis Valley.

H. Fire Weather

Fire Weather Index (FWI) and its components (e.g. Buildup Index (BUI)) are sensitive to burning conditions likely to contribute to the development of Class E fires (≥203 ha) (Kiil *et al*. 1977). Fluctuations in FWI are shown

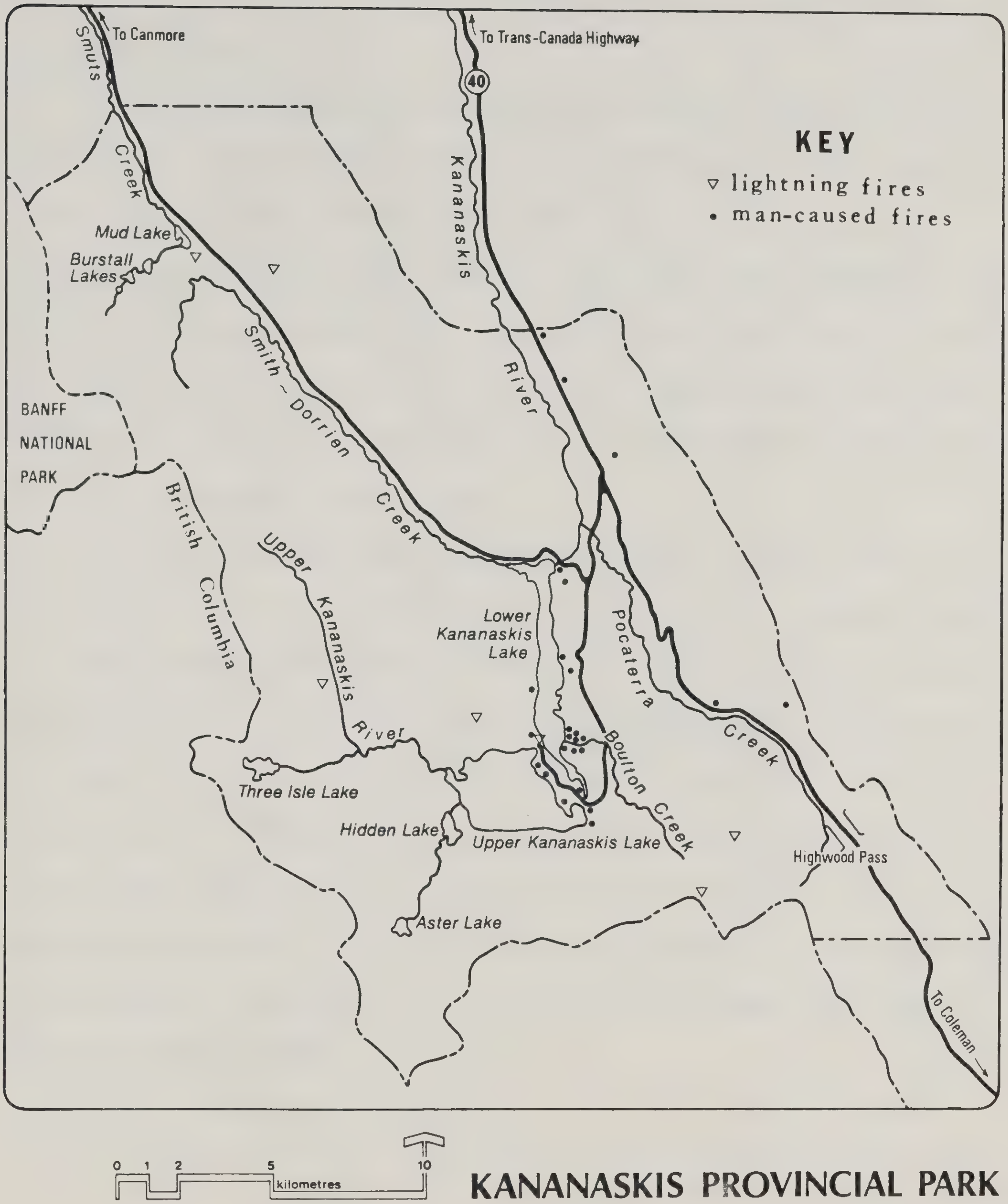

Figure 26. Location of man-caused and lightning fires for the period 1932-1977 in Kananaskis Provincial Park (from Alberta Forest Service records).

for the period 1970 to 1977 in Appendix 4. FWI fluctuated erratically over the summer months but with peaks during July and August.

Table 15 indicates that over the period 1970-1977, an average of twenty three percent (or 14 days) of July and August had a high (≥12<36) FWI and only one percent (or 1 day) had an extreme FWI (≥36). A critical fire weather summer occurred during 1971, when 45% and 7% of days in July and August had high and extreme FWI, respectively. The wet summer of 1977 had a minimum of 8% of days with high and no days with extreme FWI values.

Fluctuations in BUI are shown for the period 1970 to 1977 in Appendix 4. BUI gradually built up to a peak in July or August during most years. Table 15 indicates that over the period 1970 to 1977, seventeen percent (or 10 days) of July and August had a high BUI (≥40<75), and only four percent (or 3 days) had an extreme BUI (≥75). During 1971, twenty two percent of the days in July and August had an extreme BUI; and in 1973, thirty one percent of the days had a high BUI. A minimum of 3% high and 0% extreme BUI days occurred during 1976.

Table 15. Distribution of fire weather and buildup index values for July and August (1970-1977), Kananaskis Fire Lookout.

Fire Weather Index (FWI)

FWI Classes*		Average Percent of Total Days (%)	Average No. of Days	Max. Percent of Total Days (%)	Min. Percent of Total Days (%)
Low	<1	30	19	50	2
Moderate	≥1 <12	46	28	81	29
High	≥12<36	23	14	45	8
Extreme	≥36	1	1	7	0

Buildup Index (BUI)

BUI Classes*		Average Percent of Total Days (%)	Average No. of Days	Max. Percent of Total Days (%)	Min. Percent of Total Days (%)
Low	<20	39	24	57	16
Moderate	≥20<40	40	25	48	26
High	≥40<75	17	10	31	3
Extreme	≥75	4	3	22	0

* Class values from Grigel *et al* (1971)

IX. DISCUSSION - FUEL APPRAISAL

A. Fuel Loading

Fuel loading differences between fuel types were largely due to differences in site (soil, slope, aspect and elevation) and fire history, and their combined effects on fuel succession.[1] Fahnestock (1977) found that a heavy accumulation of coarse (≥10 cm) dead and down fuels occurred approximately 25 to 60 years and greater than 200 years since the last stand-destroying fire. The heavy accumulation in the early post-fire period was the result of fire-killed trees blowing down from the previous stand, while after 200 years, the accumulation was the result of tree mortality (mainly lodgepole pine) in the overstory. Exceptions to this general fuel successional pattern occurred with multiple burns. This was also found in Kananaskis Provincial Park, which has forest types similar to those studied by Fahnestock (1977). Fuel types 1A and 2 had a post-fire accumulation of coarse (>7.6 cm) fuels. Type 1 (same stand origin as 1A and 2) did not have a heavy coarse fuel loading because it burned three times in the past 120 years (1858, 1890 and 1920). Types 5 and 6 still reflect a post-fire accumulation of coarse fuels with 120 years since the last fire, although most of this fuel is now rotten. Types 4 and

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[1] Fuel succession is the change in biomass of the forest fuel components as forest ecosystems reestablish following a major disturbance such as fire.

7 had a heavy accumulation of coarse fuels because of tree mortality (mainly lodgepole pine) in the overstory of these stands, which are older than 200 years. Type 10 (>200 years in age) did not have a large accumulation of coarse fuels because of slower biomass accumulation at high elevation.

Fahnestock (1977) found that fine dead and down fuel (<10 cm) loading showed no apparent effect of habitat type or stand age. He also found that dead crown material was the main fuel. This also was found in Kananaskis Provincial Park except in Type 1A and 7 where small branches from the coarse dead and down material were also important fine fuels. Clagg (1975) also found little effect of stand age on fine fuel loading. High fine fuel loadings (≤7.6 cm) were found in fuel types which covered a wide range of stand ages in Kananaskis Provincial Park.

Clagg (1975) and Fahnestock (1977) found that humus biomass increased roughly with stand age. This was the main reason for variation in humus biomass between fuel types in Kananaskis Provincial Park. Another reason was diversity in fire history which gave each stand a different starting point in terms of initial humus depth. Stand differences may increase or decrease litterfall and decomposition, which would have an affect on humus biomass accumulation.

Fahnestock (1977) found that crown biomass varied due to differences in stand density, composition and stand age. This was also found for Kananaskis Provincial Park, where the highest crown biomass estimate (type 4) was a

middle-aged stand (250 years), where crown size and stand density were maximized. Type 2 had a low crown biomass estimate even though there were 15,346 trees per ha because of the small individual crown size. Type 7 also had a low crown biomass estimate even though individual crown size was large, because the number of trees per ha was small.

B. Crowning Potential

Fahnestock (1977) found crowning potential for stands similar to those in Kananaskis averaged mainly low (<4) to medium (≥4<7). Fuel types in Kananaskis Provincial Park were also rated within this range, except type 5 which had a high (≥7) crowning potential.

Fuel types 2 and 5 pose the most serious threat in terms of crowning potential within the area east of Lower Kananaskis Lake (Facility Zone) because of extensive development of facilities (i.e. values at risk). Fuel type 7 had the largest coverage over the entire Park and a moderate crowning potential.

C. Resistance to Control

Fahnestock (1977) found that resistance to control was medium to high in most units in the *Abies-Pachistima* habitat type. Medium to high resistance to control was found for most fuel types in Kananaskis Provincial Park except fuel types 9 and 10. Fuel types 1A, 2 and 5 pose the most serious problem in the Facility Zone in terms of resistance to

control.

D. Initial Rate of Spread

The construction of the Elkwood campground in fuel type 1A, which was rated high for initial rate of spread, should be a major concern to the fire control agency. A fuelbreak around the campground and fuel manipulation within or outside this facility may be necessary to reduce the hazard. Fuel type 2 covers most of the Facility Zone and also has been rated high. Fuel types 7 and 4 are a major concern in areas outside the Facility Zone.

The initial rate of spread rating is indicative of the relative length of fire perimeter to be expected. It should be of value in dispatching sufficient men and equipment to ensure prompt fire containment and as an important consideration in the location of fireline and burnout operations. Detection intensity might be increased for sites with moderate to high rate of spread ratings (Grigel *et al.* 1971).

The effect of aspect, elevation, slope and wind on the initial rate of spread ratings should not be ignored. Aspect and elevation changes affect the ambient temperature and humidity, which control the equilibrium moisture content (EMC) of all fuels. Furman (1978) found that a mountainous terrain could be stratified into a valley-bottom climate, a mid-slope climate and a high-elevation or mountain-top climate. He also found a strong aspect effect on fine fuel

moisture content. MacHattie (1966) found in the lower Kananaskis Valley that elevation had little effect on daily extreme humidities up to 305 m above the valley bottom. Above this, relative humidity increased according to the adiabatic rate (approximately 1/7th the humidity per 305 m). MacHattie (1966) found that at night there was a sharp decrease in relative humidity of 11% in the first 76.2-91.4 m above the valley bottom, and above this the decrease is 1% per 30.5 m. MacHattie (1966) emphasized the importance of this phenomenon with respect to fire hazard rating and fire control:

> "A fire in the valley bottom which shows promise of damping down at night may suddenly accelerate if it spreads a short distance upslope into a less humid (and probably windier) zone".

Furman (1978) emphasized that the danger of a fire brand igniting fuels is highest at midday in the lower elevations, while at night the ignition hazard remains fairly high at high elevations.

There are variations of aspect and elevation within fuel types in Kananaskis Provincial Park which makes adjustment difficult. The effect of aspect and elevation on the fire hazard ratings will depend on the location of the fire within the fuel type. The general guidelines mentioned previously should be used in evaluating the effects of aspect and elevation on the fire hazard rating. An adjustment was not made for each fuel type.

Slope has a significant effect on the rating of initial rate of spread. Slope changes greatly within each fuel type such that an overall adjustment cannot be made for each fuel type. Instead, data are presented from Van Wagner (1977) to allow correction of initial rate of spread for different slopes within each fuel type (Appendix 2). Appendix 2 also presents a slope determination guide for the mosaic of fuel maps (Appendix 6).

Wind has a significant effect on the rate of fire spread. Strong winds increase the rate of fire spread by tilting the flames forward so that unburned fuel receives energy by radiation and convection at an increased rate (Brown and Davis 1973). Wind also affects the combustion rate by increasing the rate of oxygen supply to burning fuel.

The effect of air movement on the rate of fire spread was modeled by Rothermel in 1972. Wind was only one of the input parameters used in the rate of spread model. In general, studies of the relationship of wind speed to rate of spread of small fires show a rapid acceleration in rate of spread with increasing wind speed (Brown and Davis 1973).

Within a forest stand, the wind speed near the ground is greatly reduced (Brown and Davis 1973). In terms of surface fires, the wind near the ground will be most important but if the forest fire crowns, then it will be influenced by the wind speed at the top of the crowns.

A foehn is a wind flowing down the leeward side of

mountain ranges where air is forced across the mountain ranges by the prevailing pressure gradient (Schroeder and Buck 1970). These winds (also called Chinooks) are common in mountain valleys such as Kananaskis during the fall and winter but can occur during the summer. Schroeder and Buck (1970) stated that "the dryness and warmth of this air combined with the strong wind flow produce the most critical fire-weather situations known anywhere". Therefore, these winds would be a critical factor in the behavior of fires in the Kananaskis Valley.

E. Fire Intensity

Fuel types 1A, 2 and 5 are the major concerns for fire control in the Facility Zone in terms of fire intensity. Fuel types 4, 6, 7 and 9 would be concerns in the rest of the Park. Fuel manipulation may be necessary in areas of heavy accumulation (e.g. Elkwood campground and blowdown along Boulton Creek Trail). This fire hazard rating is important in deciding on the suppression strategy and tactics, including kinds and quantitites of equipment (Grigel et al. 1971).

F. Lightning and Man-Caused Risk

Man-caused risk for Kananaskis Provincial Park (one every 1.2 years) compares closely with that found by Fahnestock (1977) (one every 2 years) for the Pasayten Wilderness Area, which is four times the size of Kananaskis

Provincial Park but with limited access. The impact of man-caused fires on area burned so far has been kept low. An increase in man-caused fires might be expected as use increases with the expansion of access and facilities within the Park.

Lightning fire occurrence rate has been only 5 fires per million hectares per year in Kananaskis Provincial Park. By comparison, the Pasayten Wilderness Area in Washington has had 32 fires per million hectares per year and the White Cap Wilderness Fire Study area in the Selway-Bitterroot Wilderness of Idaho and Montana has had 257 fires per million hectares per year (Fahnestock 1976). Schroeder and Buck (1970) estimated the average number of lightning fires to be 2.5 - 12 fires per million hectares per year. Simard (1975) estimated the average number of lightning fires to be 8-15 fires per million hectares per year. Kananaskis Provincial Park appears to have a relatively low lightning fire occurrence rate compared to areas in the Northwestern States and in other parts of Canada. However, the occurrence of large fires indicates lightning fire potential when burning conditions are favourable.

G. Fire Weather

The important fire weather season in Kananaskis Provincial Park is in July and August. This is also the period of greatest lightning storm activity in the Park. Fire control agencies should step up operations during these

months in Kananaskis Provincial Park. A bad fire weather summer (e.g. 1971) does not necessary mean a fire will occur, but if a fire does start then, it is more likely to develop into a large one. The limited weather data available for Kananaskis Provincial Park suggest that summers of extended high and extreme fire weather occur infrequently. The increase in use of Kananaskis Provincial Park means an ignition source (man-caused) might be more readily available during these bad fire weather periods.

X. SUMMARY AND CONCLUSIONS

A. Fire History

A fire chronology of Kananaskis Provincial Park was developed for the period 1586-1978 from fire-scarred tree wedges, age-class data and Alberta Forest Service fire records. The dates of 20 fires were identified. Major fires (>1000 hectares) occurred during 1920, 1904, 1890, 1858, 1840, 1803, 1765, 1743, 1732, 1728 and 1712 with fire intervals that ranged between 11 and 38 years. These fires accounted for 96% the total area burned from 1712 to 1978. A comparison of major fire years in Kananaskis Provincial Park and fire years determined in studies in Jasper, Alberta, nouthern U.S. Rocky Mountains and in Minnesota showed some common fire years. This suggested that subcontinental weather patterns may create favourable weather conditions for fires over a wide area.

A stand origin map, which illustrates the mosaic of age classes resulting from past fires, was constructed for Kananaskis Provincial Park. Extensive areas in the Lower Kananaskis Valley are covered by even-aged lodgepole pine stands as a result of the 1920, 1890 and 1858 fires. Remnants of older stands occur in wet depressions, on ridge tops, on south-facing slopes and at higher elevations. The distribution of age classes in Kananaskis Provincial Park was not similar to the age-class distribution of a large area in Minnescta and in Jasper National Park. The age-class

distribution in Kananaskis Provincial Park had two peaks; one at 40-120 years and the other at 320-400 years. The other two areas had only one peak at 40-120 years. The older age class found in Kananaskis Provincial Park may be due to the presence of more high-elevation forests with a longer mean fire return interval. There are no forest stands in the 0-40 age class because no major fires have occurred since 1920.

Fire-year maps were constructed which illustrate the areal extent of 20 fires from 1712 to 1973. The two largest fires occurred in 1858 (9017 ha within the Park) and 1712 (9132 ha within the Park), each covering over 17% of the total area and over 37% of the forested area of the Park. Fires in 1920, 1890, 1858, 1803 and 1712 also burned areas outside the Park boundaries. The sizes and intensities of fires in Kananaskis Provincial Park seemed to be characteristic of the higher elevation sections of other study areas in the Northern Rocky Mountains. Most fires in the lower elevation sections of Kananaskis Provincial Park (<2000 m) seem to have been large (>1000 ha), stand-destroying fires of medium to high fire intensities, with low to moderate fire intensities on the edge and backing sections. Above 2000 m in elevation, stand-destroying fires have occurred only at longer intervals (>300 years).

An analysis of prevailing wind patterns for Kananaskis Fire Lookout indicated that 83% of July and August winds

come from the west and south and are funneled down the Kananaskis Valley. These winds seemed to be a critical factor in the behavior of fires in the Kananaskis Valley. Natural fuel breaks such as the Kananaskis River have not always stopped major fires in Kananaskis. Fuel breaks could be effective in controlling the direction of burn if used as a burn-out line or keeping fires within campground areas where ignition has occurred; but the limitations of fuels management in this type of fire regime must be recognized.

The mean fire return interval (M.F.R.I.) (area-dependent expression) for major fires (>1000 hectares) in Kananaskis Provincial Park since 1712 was 21 years, with a range of 11 to 38 years. The M.F.R.I. for all fires in Kananaskis Provincial Park was 14 years with a range of 2-38 years. M.F.R.I. was calculated on a point basis to determine the effect of elevation, aspect and ecological subzone on M.F.R.I. Significant differences were found for M.F.R.I. due to elevation and aspect. M.F.R.I. was longer at high elevations and on north aspects. A "t" test of the means indicated that the two ecological subzones had significantly different M.F.R.I. The upper subalpine subzone had a longer M.F.R.I. than the lower subalpine subzone. A comparison of M.F.R.I. (point basis) in Kananaskis Provincial Park and in other areas of the Northern Rockies showed some similarities.

A good correlation was found between fire years in Kananaskis Provincial Park and a maximum latewood density

chronology for Peyto Lake, Alberta. This indicates that climate (i.e. hot and likely dry weather in August) was the major environmental factor in the occurrence of fires in Kananaskis Provincial Park, although local variations in weather, fuel conditions (loading, arrangement, continuity and fuel moisture) and topography would determine the final areal extent of the burn.

B. Fuel Appraisal

Fine dead and down loading was separated into three size classes (>0≤.64 cm, >.64≤2.5 cm and >2.5≤7.6 cm) which all showed significant differences among fuel types. Coarse (>7.6 cm) dead and down loading was separated into sound and rotten categories which both showed significant differences among fuel types. Dead and down fuel loading differences among fuel types were largely due to differences in site (soil, slope, aspect and elevation) and fire history, and their combined effects on fuel succession.

Humus and moss biomass varied significantly among fuel types. Humus biomass varied among fuel types because of differences in stand age, fire history and site. Shrub and herb biomass varied significantly among fuel types. Crown biomass varied significantly among fuel types. Crown biomass varied due to differences in stand density, composition and stand age.

Crowning potential varied significantly among fuel types. Crowning potential was generally low (<4) to moderate

(≥4<7), except in fuel type 5 which had a high (≥7) crowning potential because spruce and fir regeneration in the understory can act as ladder fuels. Fuel types 2 and 5 pose the most serious threat in terms of crowning potential within the area east of Lower Kananaskis Lake (Facility Zone) because of extensive development of facilities.

Resistance to control varied significantly among fuel types. Medium to high resistance to control was found for most fuel types in Kananaskis Provincial Park, except for fuel types 9 and 10. Fuel types 1A, 2 and 5 pose the most serious problems in the Facility Zone in terms of resistance to control.

Fuel types were rated for initial rate of spread based on differences in fine fuel loading (<2.5 cm). The construction of the Elkwood campground in fuel type 1A, which was rated high for initial rate of spread, should be a major concern to the fire control agency. Fuel type 2 covers most of the Facility Zone and also has been rated high. Fuel type 7 and 4 are a major concern in areas outside the Facility Zone.

Fuel types were rated for fire intensity based on differences in available dead and down fuel loading (all size classes). Fuel types 1A, 2 and 5 are the major concerns for fire control in the Facility Zone in terms of fire intensity. Fuel types 4, 6, 7 and 9 would be concerns in the rest of the Park.

A comparison of the overall fire hazard ratings and

fuel type areas illustrates that 65% of the forested area had a high overall fire hazard, 21% had a moderate hazard, 5.4% had a low hazard and 8.6% was not rated.

A search of Alberta Forest Service fire records indicated that on the average, less than 1 man-caused fire per year (.84 fires/year or 1 every 1.2 years), of which none exceeded .1 ha in size, was reported. An average of .26 lightning fires occurred each year (or 1 every 3.8 years), of which two exceeded class C fire size (≥40.5 ha). Many of the man-caused fires have occurred around campgrounds and along roadways. Lightning fire occurrence rate has been 5 fires per million hectares per year in Kananaskis Provincial Park. The Park appears to have a relatively low lightning fire occurrence rate compared to areas in the Northwestern States and in other parts of Canada. However, the occurrence of large fires indicates lightning fire potential when burning conditions are favourable.

The important fire weather season in Kananaskis Provincial Park is in July and August. This is also the period of greatest lightning storm activity in the Park. The limited weather data available for Kananaskis Provincial Park suggest that summers of extended high and extreme fire weather occur infrequently. The increase in use of Kananaskis Provincial Park means an ignition source (man-caused) might be more readily available during these bad fire weather periods.

XI. RECOMMENDATIONS

The following recommendations are presented in this thesis for fuels and fire management in Kananaskis Provincial Park:

1. The characteristic fire size and behavior of major fires in Kananaskis Provincial Park should be considered when planning the location and type of facilities to be constructed in the lower elevational (<2000 m) areas of the Park, and in developing initial attack plans.

2. The characteristic burn direction of fires in Kananaskis Provincial Park should be considered if fuel breaks are constructed around facilities. Fuel breaks could be effective in controlling the direction of burn if used as a burn-out line or keeping fires within campground areas where ignition has occurred; but the limitations of fuels management must be recognized.

3. It is important to be aware of the consequences of fire exclusion on plant succession and to consider alternate methods to simulate the effects of past fires to meet park management objectives, such as prescribed burning or selective removal of trees, should this be judged appropriate.

4. The construction of the Elkwood campground in fuel type 1A, which was rated high for initial rate of spread, should be a major concern to the fire control agency. A fuelbreak around the campground, and fuel manipulation within or outside this facility may be necessary to reduce the hazard.

5. Fuel manipulation may be necessary in areas of heavy dead and down accumulation to reduce fire intensities (e.g. Elkwood campground and blowdown along Boulton Creek Trail).

6. Fire control agencies should step up operations during July and August in Kananaskis Provincial Park because this is the important fire weather season and the period of greatest lightning storm activity.

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Appendix 1

Photographs of Fuel Types

Plate 1. Fuel type 1.

Plate 2. Fuel type 1A.

Plate 3. Fuel type 2.

Plate 4. Fuel type 3.

Plate 5. Fuel type 4.

Plate 6. Fuel type 5.

Plate 7. Fuel type 6.

Plate 8. Fuel type 7.

Plate 9. Fuel type 8.

Plate 10. Fuel type 9.

Plate 11. Fuel type 10.

Plate 12. Fuel type 11.

Plate 13. Fuel type 12.

Appendix 2. Relative Spread Factor by Slope Percent and Slope Angle (Van Wagner 1977) and Slope Determination Guide for Fuels Map.

Table 16. Relative spread factor by slope percent and slope angle (Van Wagner 1977) and slope determination guide for fuels map.

Slope (%)	Slope (deg.)	Spread factor	No. of 100ft. contour intervals in 1 cm on the fuels map (Appendix 6)
0	0	1.00	0
10	6	1.25	2
20	11	1.67	4
30	17	2.30	7
40	22	3.24	9
50	27	4.65	11
60	31	6.78	13
70	35	10.00	15

Appendix 3. ANOVA Tables and Regression Equations.

Table 17. ANOVA table for two-way analysis of variance (elevation and aspect vs M.F.R.I.), Scheffe multiple comparison results for aspect means and "t" test results (ecological subzone vs M.F.R.I.).

Source	Sum of Squares	Degrees of Freedom	Mean Square	Computed F	Probability
Elevation	96610.50	1	96610.50	6.38	.025*
Aspect	140989.30	3	46996.43	3.10	.050*
Interaction	94147.00	3	31382.33	2.07	>.100
Error	1332866.75	88	15147.35		

* significant according to the confidence level set in this study (95%)

Scheffe multiple comparison (95% confidence level) indicated that the difference between aspect means had to be >83.9 to be significant.

"t" Test Results

	Mean	Variance (S^2)	No. of Observations
Upper Subalpine Subzone	304	5768.8	13
Lower Subalpine Subzone	101	13329.6	88

Common Variance (S^2p) = 12539.52

Value of t = 6.101

Critical T is >1.645 at 95% confidence level, therefore t is significant.

Table 18. ANOVA tables for one-way analysis of variance (fuel loading, crowning potential and resistance to control).

	Source	Sum of Squares	Degrees of Freedom	Mean Square	Computed F	Probability
Fine Fuel Dead and Down Loading ($>0\leq.64$ cm)	Column	2.1120	9	0.2347	5.3877	<.001
	Error	13.0671	300	0.0436		
	Total	15.1791	309			
Fine Fuel Dead and Down Loading ($>.64\leq2.54$ cm)	Column	69.6078	9	7.7342	8.5492	<.001
	Error	271.4023	300	0.9047		
	Total	341.0101	309			
Fine Fuel Dead and Down Loading ($>2.54\leq7.62$ cm)	Column	417.1960	9	46.3551	6.8117	<.001
	Error	2041.5680	300	6.8052		
	Total	2458.7640	309			
Coarse Fuel Dead and Down Loading (>7.62 cm) Rotten	Column	90954.6112	9	10106.0680	49.6915	<.001
	Error	61012.9091	300	203.3764		
	Total	151967.5203	309			
Coarse Fuel Dead and Down Loading (>7.62 cm) Sound	Column	19145.8433	9	2127.3159	21.0897	<.001
	Error	30260.9627	300	100.8699		
	Total	49406.8060	309			

Table 18. Continued.

	Source	Sum of Squares	Degrees of Freedom	Mean Square	Computed F	Probability
Coarse Fuel Dead and Down Loading (>7.62 cm) Rotten + Sound	Column	108113.3428	9	12012.5930	37.7951	<.001
	Error	95350.4361	300	317.8348		
	Total	203463.7789	309			
Total Dead and Down Loading (all size classes)	Column	112736.3772	9	12526.2640	37.0593	<.001
	Error	101401.7585	300	338.0059		
	Total	214138.1357	309			
Dead and Down Fuel Depth	Column	5658.7886	9	628.7543	20.2604	<.001
	Error	28550.9071	920	31.0336		
	Total	34209.6957	929			
Humus Biomass	Column	173004.5726	9	19222.7330	5.2449	<.001
	Error	2235684.1207	610	3665.0559		
	Total	2408688.6933	619			
Moss Biomass	Column	276.1595	10	27.6160	45.4295	<.001
	Error	96.6539	159	0.6079		
	Total	372.8134	169			
Shrub Biomass	Column	1815467.1616	10	181546.7200	4.5261	<.001
	Error	6377615.3877		40110.7886		
	Total	8193082.5493				

Table 18. Continued.

	Source	Sum of Squares	Degrees of Freedom	Mean Square	Computed F	Probability
Shrub Height	Column	27979.9985	10	2797.9998	28.4294	<.001
	Error	15648.6500	159	98.4192		
	Total	43628.6485	169			
Herb Biomass	Column	11906.7752	10	1190.6776	12.0400	<.001
	Error	15724.0469	159	98.8934		
	Total	27630.8221	169			
Crown Biomass	Column	13881151000.0	8	1735143900.0	12.2033	<.001
	Error	18626439885.0	131	142186450.0		
	Total	32507590885.0	139			
Crowning Potential	Column	311.4027	9	34.6003	18.2560	<.001
	Error	274.8167	145	1.8953		
	Total	586.2194	154			
Resistance to Control	Column	15.8036	9	1.7560	27.8076	<.001
	Error	9.1562	145	0.0631		
	Total	24.9598	154			

Table 19. Spruce and pine regression equations and multiple comparison results of regression slopes for D.B.H. vs crown width, and subalpine fir regression equations for D.B.H. vs crown length and D.B.H. vs total tree height.

Spruce Regressions (D.B.H. vs Crown Width)

Fuel Type	Regression Equations	Source	Sum of Squares	Degrees of Freedom	Mean Square	Computed F	Probability
1	$y=1.1490x + 2.2489$	Regression	6583.8322	12	598.5302	217.4266	<.001
1A	$y=0.7515x + 4.9018$						
4	$y=0.4357x + 5.3270$	Error	151.4036	60	2.5234		
5	$y=0.2893x + 7.3191$						
6	$y=0.5130x + 4.0540$	Total	6735.2358	72			
7	$y=0.5424x + 3.3059$						
		$R^2=.9775$					

y= crown width (ft.)
x= D.B.H. (in.)

Scheffe multiple comparison (95% confidence level) indicated that the difference between regression slopes had to be ≥ 4.3047 to be significant.

All Fuel Types Combined	Source	Sum of Squares	Degrees of Freedom	Mean Square	Computed F	Probability
* $y=0.4059x + 5.5637$	Regression	6538.5624	2	3269.2812	1163.6027	<.001
	Error	196.6734	70	2.8096		
	Total	6735.2358	72			
	$R^2=.9708$					

* regression used in crown biomass calculations

Table 19. Continued.

Pine Regressions (D.B.H. vs Crown Width)

Fuel Type	Regression Equations	Source	Sum of Squares	Degrees of Freedom	Mean Square	Computed F	Probability
1	y=1.3625x + 0.3480	Regression	10125.5500	14	723.2535	289.8567	<.001
1A	y=1.4387x + -0.9526						
2	y=0.6493x + 1.1023	Error	361.8055	145	2.4952		
3	y=0.8499x + 0.3755						
4	y=0.5355x + 2.0113	Total	10487.3548	159			
5	y=0.9886x + -0.0079						
6	y=0.9076x + 1.4383	R^2=.9655					

y= crown width (ft.)
x= D.B.H. (in.)

Scheffe multiple comparison (95% confidence level) indicated that the difference between regression slopes had to be ≥3.7600 to be significant.

All Fuel Types Combined	Source	Sum of Squares	Degrees of Freedom	Mean Square	Computed F	Probability
*y=0.9971x + 0.5426	Regression	9563.4711	2	4781.7356	812.5831	<.001
	Error	923.8839	157	5.8846		
	Total	10487.3548	159			
	R^2=.9119					

* regression used in crown biomass calculations

Table 19. Continued.

Subalpine Fir Regressions

D.B.H. vs Crown Length	Source	Sum of Squares	Degrees of Freedom	Mean Square	Computed F	Probability
y=3.2789x + 9.3727	Regression	39844.0330	2	19922.0160	367.4743	<.001
y= crown length (ft.)	Error	1897.4675	35	54.2134		
x= D.B.H. (in.)	Total	41741.5000	37			
	R^2=.9545					

D.B.H. vs Total Height	Source	Sum of Squares	Degrees of Freedom	Mean Square	Computed F	Probability
y=4.3705x + 13.1640	Regression	72913.1420	2	36456.571	415.1070	<.001
y= total height (ft.)	Error	3073.8583	35	87.8245		
x= D.B.H. (in.)	Total	75987.0000	37			
	R^2=.9595					

Appendix 4. Fire Weather Distribution for the Period 1970 to 1977.

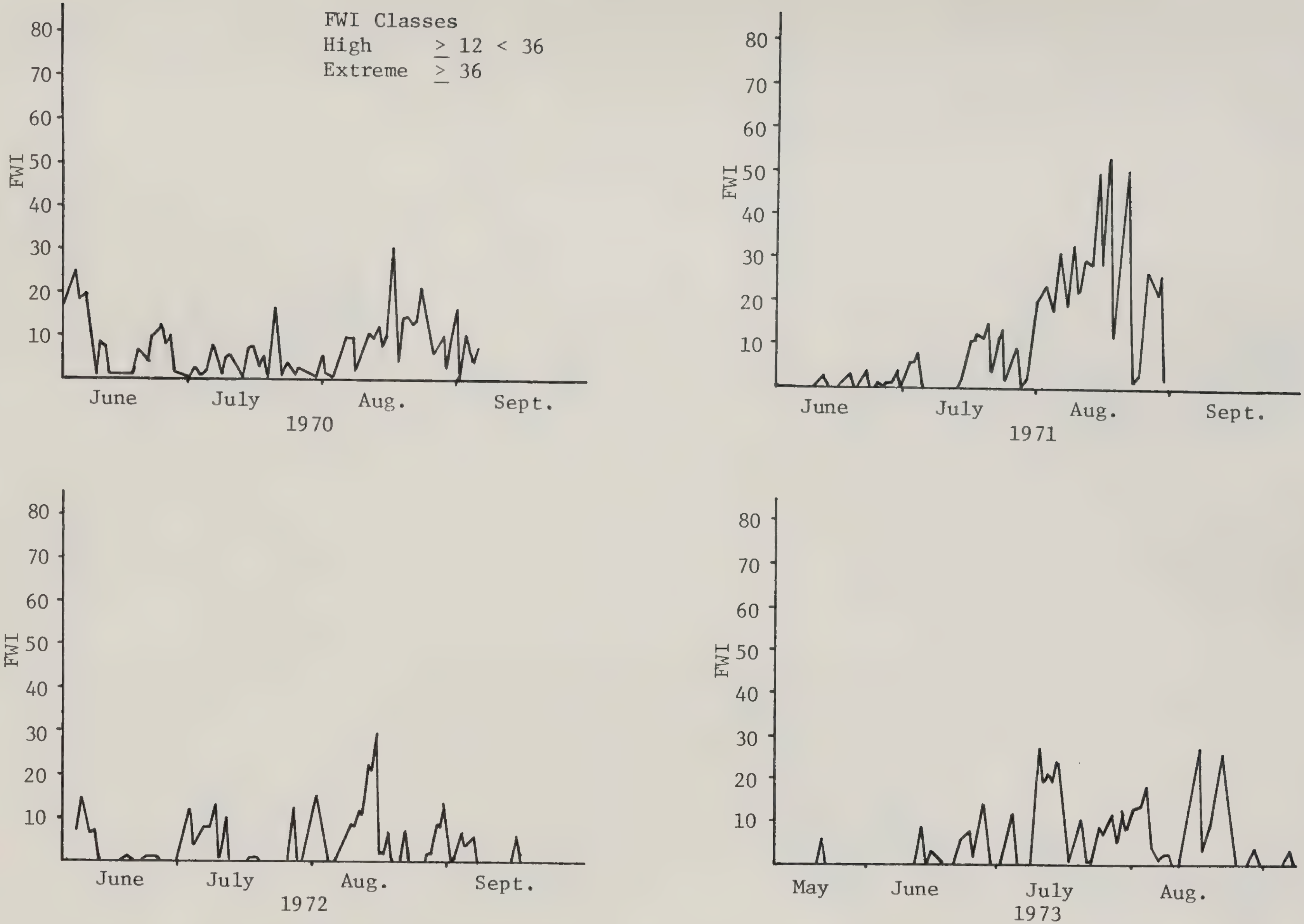

Figure 27. Fire weather index distributions for Kananaskis Fire Lookout (1970-1973).

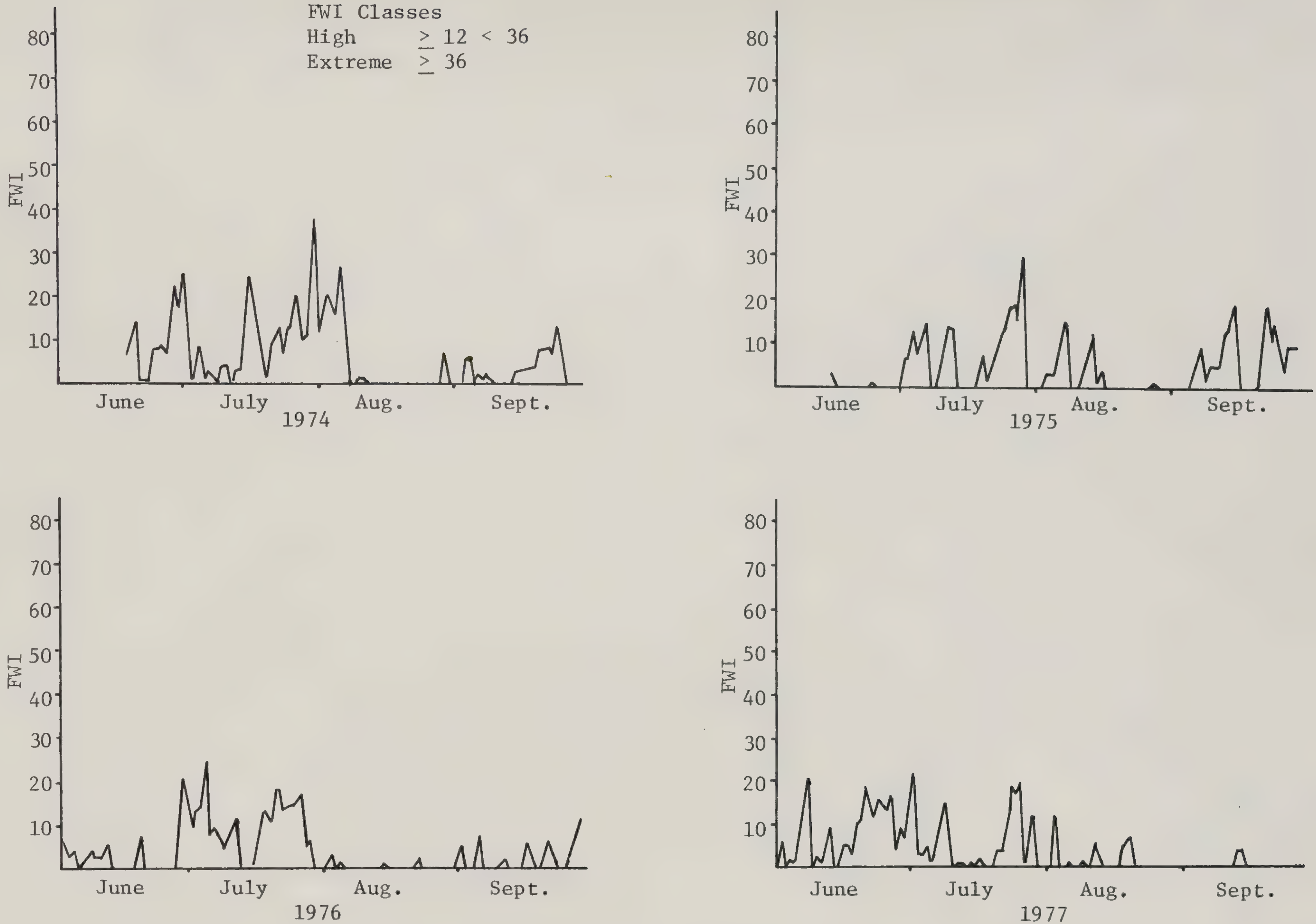

Figure 28. Fire weather index distributions for Kananaskis Fire Lookout (1974-1977)

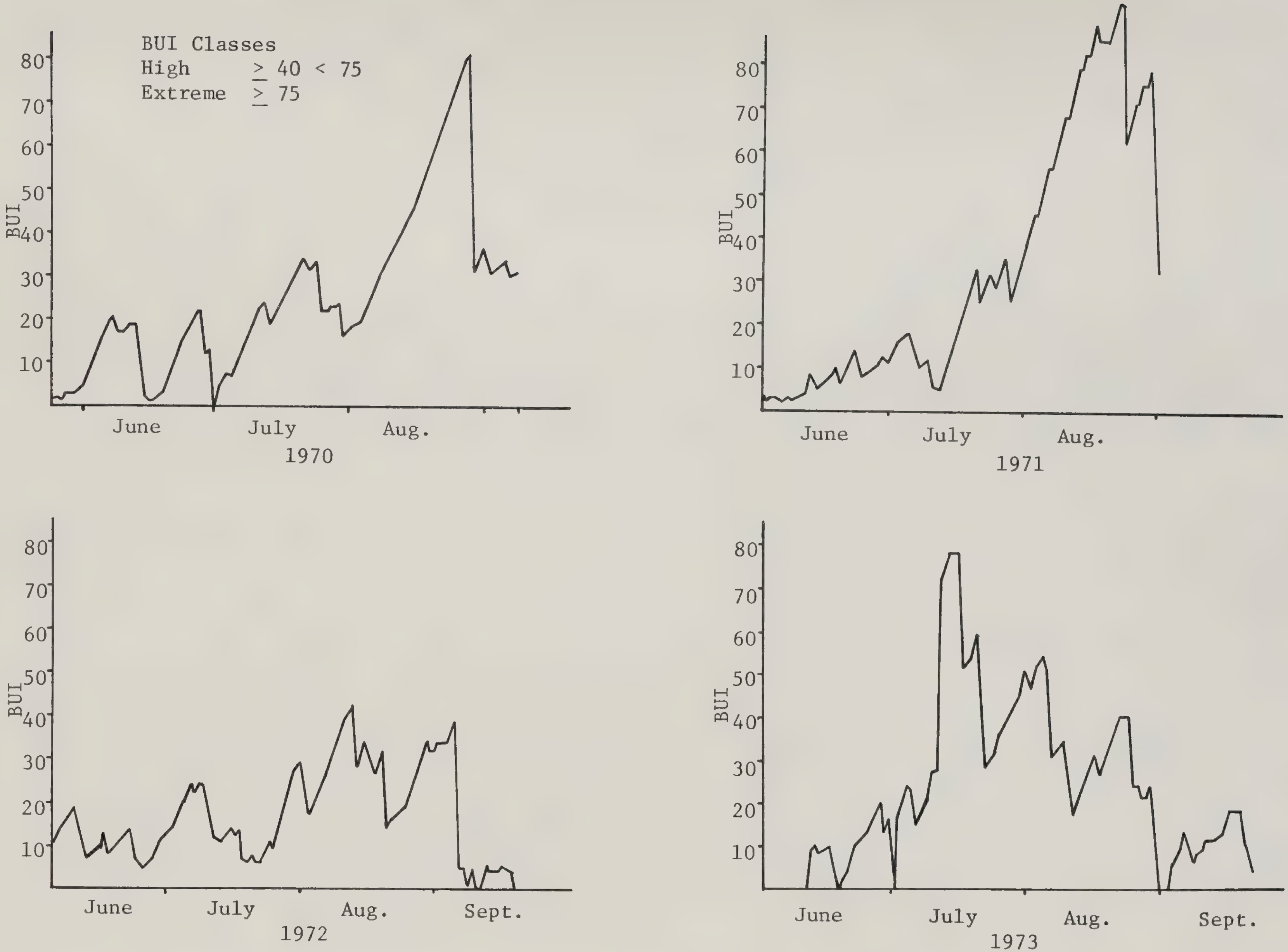

Figure 29. Buildup index distributions for Kananaskis Fire Lookout (1970-1973)

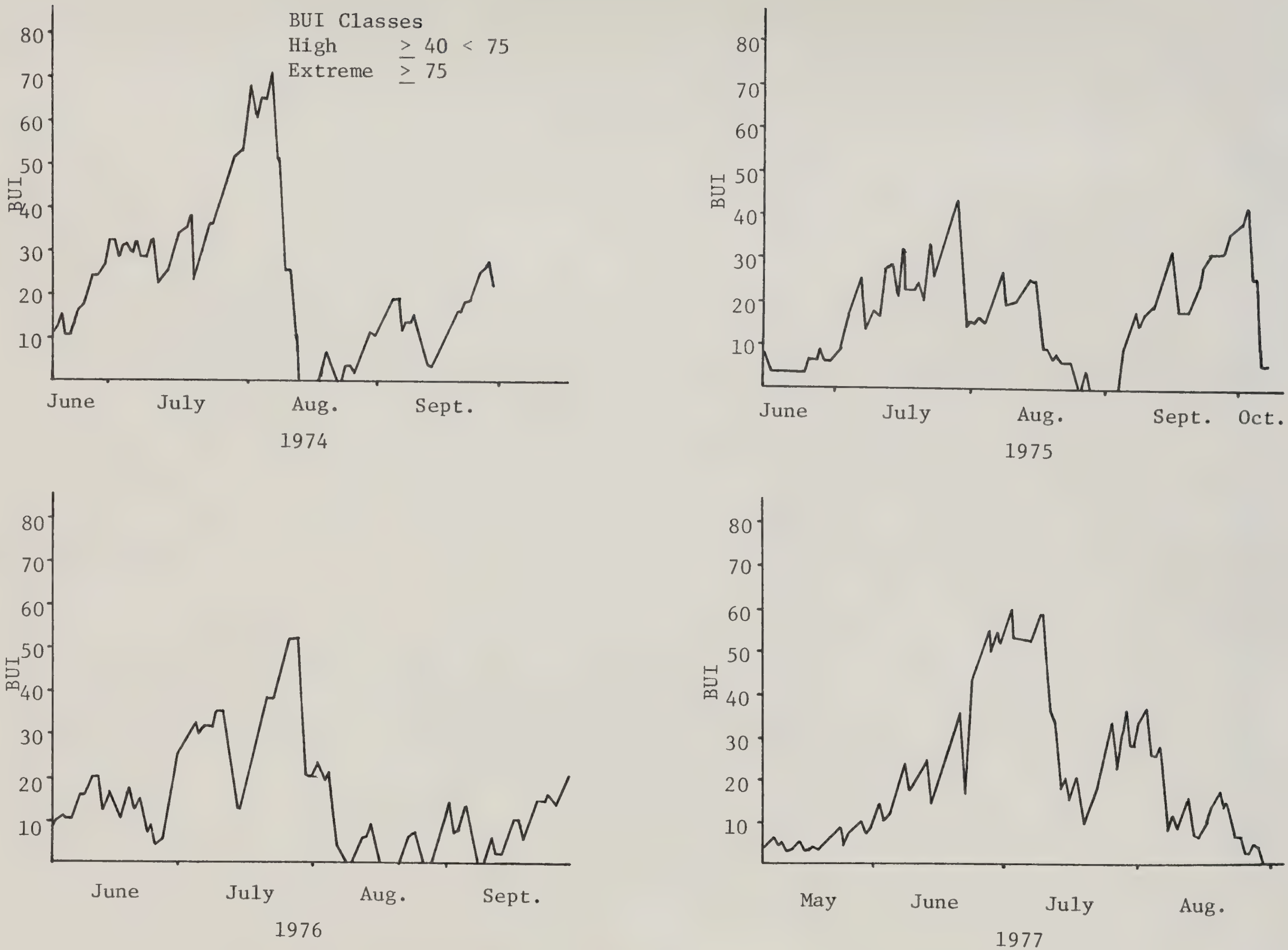

Figure 30.Buildup index distributions for Kananaskis Fire Lookout (1974-1977)

Appendix 5. Figure 31. Mosaic of stand origin maps.

Appendix 6. Figure 32. Mosaic of fuel type maps.

FUELS MAP
KEY

Fuel Type	Description	Initial Rate of Spread (IRS)	Fire Intensity (FI)	Crowning Potential (CP)	Resistance to Control	Overall Fire Hazard
1	1920 ORIGIN LODGEPOLE PINE WITH AN OPEN APPEARANCE, LITTLE DEAD AND DOWN MATERIAL AND A WELL DEVELOPED SHRUB LAYER.	L	L	L	M	$L^{IRS,FI,CP}$
1A	1920 ORIGIN LODGEPOLE PINE WITH AN OPEN APPEARANCE, MUCH DEAD AND DOWN MATERIAL AND A WELL DEVELOPED SHRUB LAYER.	H	H	L	H	$H^{IRS,FI}$
2	1920, 1904 AND 1890 ORIGIN LODGEPOLE PINE WITH A DENSE APPEARANCE, MEDIUM AMOUNT OF DEAD AND DOWN MATERIAL AND A POORLY DEVELOPED SHRUB LAYER.	H	M	M	H	H^{IRS}
3	1890 AND 1858 ORIGIN LODGEPOLE PINE WITH A MEDIUM TREE DENSITY, WITH LITTLE DEAD AND DOWN MATERIAL, MOST STANDS SHOW THINNING BY FIRE, NO SPRUCE/FIR UNDERSTORY (IE. LADDER FUELS).	M	L	M	M	$M^{IRS,CP}$
4	150 TO 300 YEAR OLD LODGEPOLE PINE, TRANSITION STAND TO OLD GROWTH, A GOOD COMPONENT OF SPRUCE IN THE OVERSTORY AND MUCH DEAD AND DOWN MATERIAL.	H	M	M	H	H^{IRS}
5	1904, 1890 AND 1858 ORIGIN LODGEPOLE PINE WITH A MEDIUM TREE DENSITY, MEDIUM AMOUNT OF DEAD AND DOWN MATERIAL AND SPRUCE/FIR UNDERSTORY (IE. LADDER FUELS).	M	H	H	H	$H^{FI,CP}$
6	1904 AND 1858 ORIGIN LODGEPOLE PINE WITH AN OPEN STAND APPEARANCE, DOMINATED BY SPRUCE AND FIR IN THE OVERSTORY.	L	M	M	M	$M^{FI,CP}$
7	300+ YEAR OLD SPRUCE WITH DEAD LODGEPOLE PINE IN THE OVERSTORY AND MUCH DEAD AND DOWN MATERIAL.	H	H	M	H	$H^{IRS,FI}$
8	BOGS AND FENS.					
9	RECENT BURNS (1967 AND 1973)	L	M	L	L	M^{FI}
10	300+ YEAR OLD SPRUCE/FIR/ALPINE LARCH COMPLEX AT HIGH ELEVATION.	L	L	M	L	M^{CP}
11	PARTIAL CUT AREAS (NOT SAMPLED).					
12	CLEARCUTS (NOT SAMPLED)					

L = Low M = Moderate H = High

KANANASKIS PROVINCIAL PARK

A Fire History

OVINCIAL PARK

Resource Inventory

A Fire History and Fuel Appraisal Study

Brad Hawkes, 1978